CREDA

Yukon 17

Pelly Crossing Wood Chip Boiler

CREDA is a program which has been jointly funded by Energy, Mines and Resources, Canada and the Yukon Government, Department of Economic Development and Tourism. For more information or copies of reports contact the Energy and Mines Branch, Yukon Government, Box 2703, Whitehorse, Y1A 2C6.

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FOREWORD

The availability of secure and affordable energy supplies is a subject of national concern. Our primary energy sources are becoming more costly and less accessible. However, Canada has both the resources and technical expertise needed to develop renewable and alternative sources of energy.

The Governments of Yukon and Canada have entered into a Conservation and Renewable Energy Demonstration Agreement as one means of pursuing this end. Cost shared by the Federal and Yukon Governments, CREDA has a budget of $3.3 million and is dedicated to the development and demonstration of conservation and renewable energy technologies.

The objectives of CREDA are:

- To develop and demonstrate promising new technologies, which, when widely adopted, will exploit renewable resources, conserve energy and/or use energy more efficiently.
- To develop broad public awareness of the potential of renewable energy and conservation technology.
- To provide opportunities for the commercial application of the technologies.
- To create economic spin-off benefits for manufacturing, industry and commerce.
- To create employment in new or existing energy-related industries.

The Pelly School wood chip project which is discussed in the following pages is an attempt to demonstrate, particularly for the large scale energy users in Yukon, the viability and cost effectiveness of wood chip heating. This inexpensive renewable energy source is in great supply in Yukon and in addition to reducing heating costs, creates a source of local employment. The widespread adoption of this heating technology would go far in reducing Yukon's energy dependency on outside sources.

EXECUTIVE SUMMARY

The Pelly wood chip project has demonstrated that wood chips are a successful fuel for space and domestic water heating in a northern climate. Pelly Crossing was chosen as a demonstration site for the following reasons: its extreme temperatures, an abundant local supply of resource material, the high cost of fuel oil heating and a lack of local employment.

The major obstacle to the smooth operation of the Vyncke WW 300S wood chip boiler system has been the poor quality of chip supply. Oversize chips and splinters have created blockages in the feed system resulting in the system's breakdown, damage to the augers and excessive personhours consumed in the system's operation and maintenance. These problems have been compounded by the time and expense required for repair.

The production of poor quality chips has been caused by inadquate operation and maintenance of the Bruks 722 chipper. Dull knives and faulty anvil adjustments produced chips and splinters far in excess of the one centimetre size specified for the system's design. The problem of chip quality has been alleviated by the Government of Yukon's assumption of responsibility for the operation and maintenance of chip production.

Unanticipated complications have caused costs of the system to be higher than expected by approximately $15,000. The actual cost of the project was approximately $165,000. The first year of the system's operation was expected to accrue $11,600 in heating cost savings. Unfortunately, this estimate was impossible to confirm given the system's irregular operation and incremental costs. Consistent operation of the system for a period of at least one year plus the installation of monitoring devices will allow the cost effectiveness to be calculated.

The wood chip system's impact on the environment was estimated to be minimal. Wood chip burning was considered cleaner and safer than cordwood burning.

There is great replication potential for the project in Yukon where space heat requirements of 3.5 petajoules can be satisfied by 10 per cent of Yukon's estimated sustained annual yield. Commercial and business entities have expressed interest in the wood chip heating concept but they are wary on account of the Pelly project's unfavourable reputation. Although the Pelly project is a relatively successful demonstration, replication can only be assured through a successful wood chip demonstration which is more accessible to both maintenance centres and public viewing and evaluation.

Résumé pour l'exécutif

Le projet d'utilisation des copeaux de bois mis sur pied à Pelly Crossing a démontré que les copeaux de bois sont un combustible adéquat pour le chauffage soit d'une surface de l'air soit de l'eau chaude domestique dans un climat nordique. On avait choisi Pelly Crossing comme site de démonstration pour les raisons suivantes: ses températures extrêmes, une abondante réserve locale de matières premières, le coût élevé du mazout et le manque d'emplois dans la localité.

L'obstacle majeur au bon fonctionnement de la chaudière Vyncke WW 300S qui utilise des copeaux de bois comme combustible a été la mauvaise qualité de l'approvisionnement en copeaux. Des copeaux et des éclats de bois trop gros ont occasionné l'obstruction du système d'alimentation ce qui a causé des pannes de chauffage, abîmé les pelles-cuvettes et abouti à une utilisation excessive de personnes-heures pour l'opération et l'entretien du système. Ces problèmes ont été aggravés par le temps nécessaire aux réparations et les dépenses qu'elles ont occasionnées.

La production de copeaux de bois de mauvaise qualité a été causée par une utilisation et un entretien inadéquats du déchiqueteur Bruks 722. Des couteaux émoussés et des enclumes mal ajustées ont produit des copeaux et des éclats beaucoup plus gros que le format d'un centimètre recommandé pour le bon fonctionnement du système. Le problème causé par la mauvaise qualité des copeaux a été réduit quand le Gouvernement du Yukon a pris en charge l'opération et l'entretien du système produisant les copeaux de bois.

Des complications inattendues ont porté le prix de revient du système à 15.000$ de plus que prévu. Le coût réel du projet s'est élevé à environ 165.000$. La première année d'opérations devait faire réaliser des économies de chauffage de 11.600$. Malheureusement, il a été impossible de confirmer cette estimation vu l'opération irrégulière du système et les dépenses additionnelles non prévues. Il sera cependant possible de calculer la rentabilité du projet lorsque le système aura fonctionnée sans interruption pendant au moins un an et que des dispositifs de contrôle et de surveillance auront été installés.

On estimait que le système utilisant des copeaux de bois comme combustible aurait un impact minime sur l'environnement. On considérait que c'était plus propre et plus sûr que du bois de corde.

Il y a au Yukon de grandes possibilités de répéter le projet. En effet, les besoins énergétiques annuels du Yukon sont de 3,5 petajoules qui peuvent être produits par l'utilisation de 1/200^{e} des 750.000 hectares de combustible biologique potential recouvrant le Territoire. Des entreprises commerciales et des maisons d'affaires ont indiqué qu'elles s'intéressaient au concept du chauffage aux copeaux de bois mais elles demeurent sur leurs gardes à cause de la réputation plutôt mauvaise du projet de Pelly Crossing. Bien que le projet de Pelly Crossing constitue une démonstration de chauffage aux copeaux de bois relativement réussie, la répétition du projet ne peut être assurée que si l'on fait une démonstration bien réussie qui ait lieu dans un endroit plus accessible, favorisant ainsi non seulement l'entretien du système mais également son inspection et évaluation par le public.

INTRODUCTION

Through the Canada/Yukon Conservation and Renewable Energy Demonstration Program, the Government of Yukon undertook to demonstrate the viability of using an abundant local renewable resource (wood biomass) to provide space and domestic water heating in remote Yukon communities. Two associated projects were funded for the demonstration at the community of Pelly Crossing. The location of the community in relation to other Yukon communities is shown on Figure 1.

Through the CREDA program, a large scale project was funded to demonstrate that wood chips are a viable source of space heating for a large building subjected to northern climatic conditions. The Department of Education, Government of Yukon received $97,500 for the installation of a wood chip heating system in the new school built at Pelly Crossing.

A second project funded the Selkirk Indian Band located in the same community to supply the wood chips. The objectives of this demonstration were to promote the commercial production, distribution and consumption of wood chips in central Yukon communities and to demonstrate the full range of development possible within the local woodchip industry. CREDA funding for this project was $71,500 and taken together, both projects involved a total capital expenditure of $214,000.

As an alternative to high heating costs, energy conservation and the development of renewable resources for energy sources offers Northerners two means for reducing their energy costs. In the North, remote communities particularly suffer from high energy costs. Table 1 outlines the 1984 prices of heating oil in various Yukon communities. Also, the economies of these remote communities are most vulnerable to increases in world prices such as was experienced during the 1970's oil crisis.

Figure 1 Map of Yukon

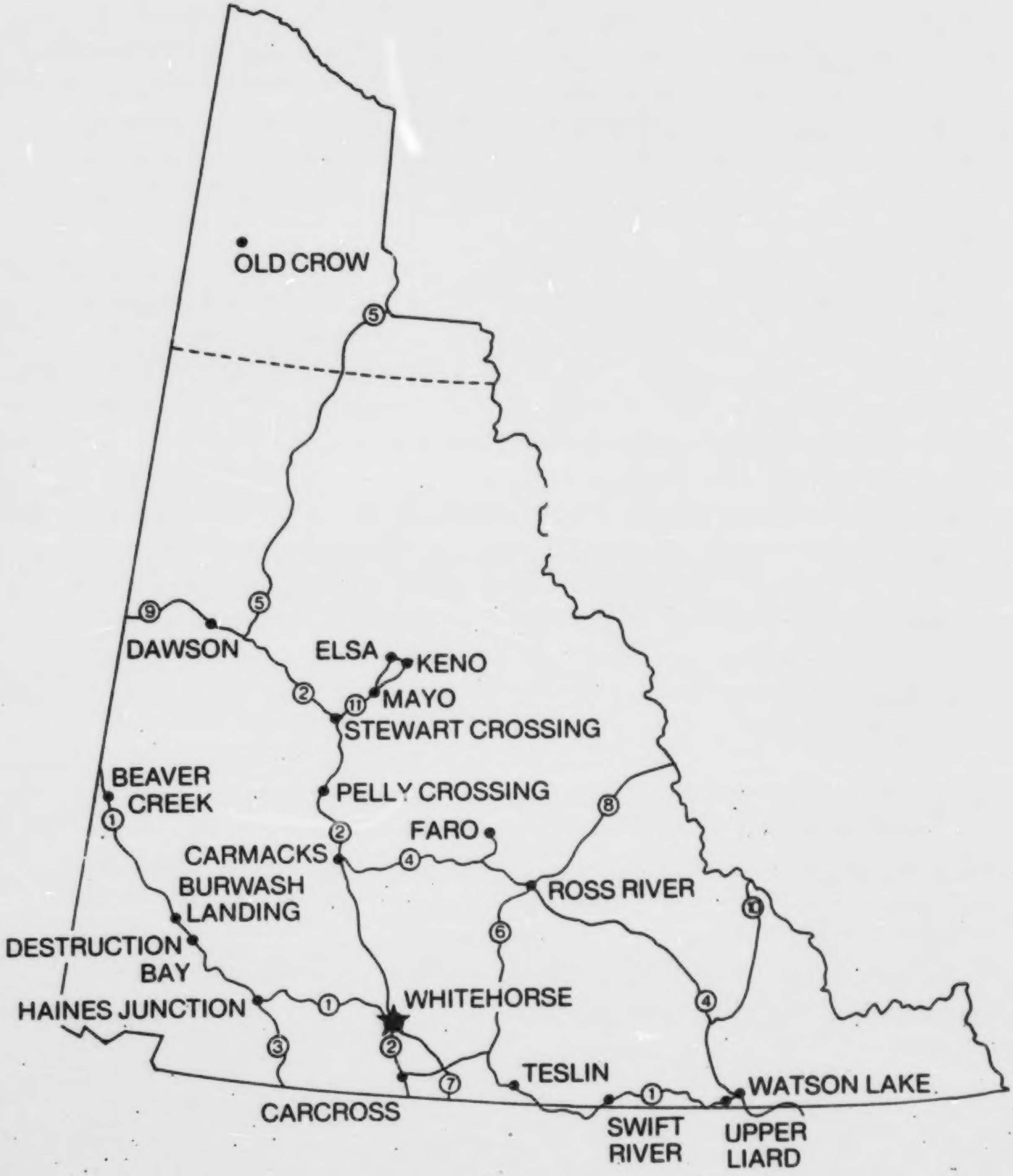
OLD CROW
5
9
DAWSON
5
ELSA
KENO
2
11
MAYO
STEWART CROSSING
BEAVER CREEK
PELLY CROSSING
1
2
FARO
8
CARMACKS
4
ROSS RIVER
BURWASH LANDING
10
6
DESTRUCTION BAY
HAINES JUNCTION
1
WHITEHORSE
4
3
2
TESLIN
7
1
WATSON LAKE
CARCROSS
SWIFT RIVER
UPPER LIARD

TABLE 1

(AVERAGE) HEATING OIL PRICES IN YUKON

Community	Population*	Price (¢/litre)** Furnace Grade	Price (¢/litre)** Stove Grade
Carcross	257	-	50.0
Dawson City	1,323	49.4	50.7
Destruction Bay	65	-	46.3
Faro	1,309	46.7	47.8
Haines Junction	465	-	45.4
Mayo	455	-	55.0
Teslin	349	-	45.8
Watson Lake	1,317	-	43.2
Whitehorse	16,098	43.1	-

* Department of Economic Development and Tourism, Government of Yukon: Yukon Economic Review Third Quarter, 1984.

** Statistical Services Branch, Department of Economic Development and Tourism, Government of Yukon.

Yukoners currently spend a considerable amount of money to heat their homes and businesses with petroleum products which must be imported. In 1983, approximately 49,820 m^3 of stove oil/kerosene and light fuel oil was consumed for space and domestic water heating.[1] Assuming an average price of .45¢ per litre, Yukoners spent approximately $22.5 million on these fuels. Therefore, it would be to Yukon's benefit to produce a good share of this money locally by substituting these hydrocarbon fuels with a renewable resource, namely wood.

In 1983, a symposium held in association with the 34th Alaska Science Conference in Whitehorse focussed exclusively on the possibility of gaining energy self sufficiency in the North through energy conservation and forest biomass. During an opening address by the Minister for Economic Development, Government of Yukon, the forests in Yukon were identified as a vast untapped renewable resource which could support an energy industry to reduce heating

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1. Department of Economic Development and Tourism, Government of Yukon: Yukon Economic Review Third Quarter, 1984 pg. 74.

fuel costs as well as to promote social and economic development in Yukon's communities. The Minister pointed out the benefits that can occur.[2]

> We have calculated that by supplying 35 per cent of our energy needs in Yukon we would create over 200 jobs: jobs for researchers, harvesters, truck drivers, full-time jobs and seasonal jobs. That in itself is significant and when you consider the spin-offs in the local economy from the employment and from the money that will no longer be leaving to pay for oil bills, you can begin to appreciate the impact this can have.

The Yukon economy is undiversified, presently relying heavily on the government, mining and tourism sectors and in that order of importance. In September, 1984, there were only 22 business establishments in the forestry sector and these businesses together employed less than one percent of the full time workers in Yukon.[3]

To help alleviate the financial burden imposed by the use of imported fuel oil, the wood chip heating system installed in the Pelly Crossing school was considered ideal for several reasons. First, in line with the Federal Government's initiative to reduce national dependence on non-renewable imported hydrocarbons, heat is supplied by a locally abundant renewable resource. A large area surrounding Pelly Crossing was stricken by forest fire in 1969 providing an abundant supply of fire killed wood at minimal cost. By comparison, the price of fuel oil in Pelly Crossing would be approximately .46¢ per litre (1984 price).

Secondly, the system was installed to stimulate a local chipping industry to create local employment. It was estimated that a wood chipper operation of this nature creates at least two to three seasonal jobs and that more jobs would be created if the demand for chips rose as other energy consumers converted to wood chip heating. Since Yukon has an enormous biomass energy potential which is presently utilized only for cordwood, it was anticipated that the successful demonstration of the Pelly Crossing projects would pave the way for replication and open up this energy potential. An excellent target audience is Yukon's commercial, industrial and institutional sectors whose heating requirements could be supplied by the larger heating capacity.

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[2] Government of Yukon, Energy Conservation and Forest Biomass, 1983.

[3] Department of Economic Development and Tourism, Government of Yukon Yukon Economic Review Third Quarterly, 1984 pg. 15 and 78.

In considering the success or failure of the Pelly wood chip project, it is important to realize the features which make it unique. The project cannot be divorced from its setting, namely a small relatively isolated community, lacking any type of equipment repair facility. It is, therefore, not simply the scientific demonstration of an alternative energy heating system which can be objectively judged as good or bad. It's success must be determined relative to the management of the project and the operating conditions.

The following technical review will discuss in detail the performance of the wood chip heating system and the wood chip production operation. The economic realities of each project are assessed separately using budget reviews and analyzing the economics for potential replication. The impacts of the heating system and chipping business are discussed under social, economic and environmental impacts and the possibilities for commercialization are also addressed.

ADVANTAGES TO WOOD CHIP HEATING

Potentially, Yukon's forests can supply wood fuel energy from two different sources: milling residues and wood biomass. Milling residues are available in the form of bark, sawdust, shavings, slabs and chips and these waste products are currently burned by the sawmill operators. In 1982, the forest industry in Yukon produced 3,100 m^3 of round timber and 13,800 m^3 of lumber.[4]

Assuming that every m^3 of lumber produces an equivalent amount of wood waste, the wood residues from the lumber industry equal a heating equivalence of 120,000 GJ which equals approximately 3 million litres of heating oil.

Wood biomass includes logging slash, roadside trees, commercial cutting and firekill. This source is used in the Yukon extensively in the form of cordwood. Heating homes with cordwood cut from firekill areas is a common practise whereby woodcutters in the Yukon produced 90,000 m^3 of cordwood in 1982.[5] The major firekill areas accessible by communities are located in the areas of Watson Lake, Whitehorse and Pelly Crossing.

The Yukon Government's resident alternative energy expert, Bob Collins, estimates that more than a third of the energy Yukoners consume annually for heat could be produced by woodchip fuel. From the Yukon's four million hectares of accessible and productive forest, he predicts that wood chip heating would create 200 jobs and could save Yukoners $10 million a year now spent on fuel oil.

Wood heat is already used extensively by homeowners in the Yukon who prefer to heat their homes with cordwood. The business community, on the other hand, has been reluctant to convert to cordwood heating as an alternative to high fuel oil heating because of the amount of handling and monitoring required. Experts from the Energy Branch, Government of Yukon, suggest that wood chips could provide an acceptable alternative and is within the realm of economic possibility for Yukon entrepeneurs as a heat source if produced locally.

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[4] Ibid. p. 73

[5] Ibid.

There are several advantages to using wood chips rather than the conventional stick or chunk forms which promote its acceptibility for the business sector.

One significant advantage is the increased energy savings that can be achieved from burning wood chips instead of cordwood. Chunk fuelwood heaters typically operate at about 50 to 60 percent combustion efficiency and 35 to 40 percent seasonal efficiency. Chip furnaces, on the other hand, operate between 70 to 80 percent combustion efficiency and produce a seasonal efficiency of about 60 percent.

A wood chip industry can increase wood fuel markets thus providing business incentives for local economies. In the Yukon, an opportunity exists for woodlot owners to develop the industry from currently unused milling wood waste as well as chipping the limbs, tops of commercial trees, weed species and small trees. Since wood chips can be produced locally, money will flow directly to the communities and the workforce will increase. Besides providing business opportunities in the production of chips, local service businesses can profit through the sales and servicing of both harvesting and wood chip burning equipment.

In chip form, wood fuel is more convenient than cordwood, thus the concerns expressed by the business sector regarding handling can be easily overcome. It can be transported and distributed easily from the supply site to wood burning customers. And, it is convenient for the operator as the heating system will feed itself automatically requiring only that the chip hopper or silo be filled periodically. The frequency of attention depends upon the size of the chip storage bin and on the amount of heat required. For the large heating needs of institutions and industries, stoker bins capable of holding upwards to two tonnes of chips are usually installed. Thus, refuelling by the operator is eliminated since the bin can be filled on a preplanned delivery schedule similar to fuel oil delivery systems.

Higher standards of air quality can be achieved with wood chip burners versus cordwood furnaces. In centres like Whitehorse where woodsmoke is already a pollution problem, the efficient levels of burning which can be achieved are important for air quality control. Chips are more uniform in quality leading to cleaner and more efficient burning. In a well designed stoker, the fuel is burned in a small, very hot fire which burns it completely. The wood chip fuel is mechanically added to the fire by a stoker only when heat is required. As a consequence, there is little or no visible smoke, limited creosote deposits to pose fire hazard and little air pollution.

Wood chip burning is not entirely problem free and the efficiency of a wood chip burning system is greatly dependent upon the quality of the wood chip supply. Excessive levels of moisture in the supply is the most objectionable characteristic to the use of wood biomass. Moisture is native to biomass in levels between 20 to 80 percent and a minimal of 20 per cent moisture is vital to controlled efficient firing of biomass (free suspension firing being the exception). However, levels above 30 per cent may require predrying and to predry in a dryer is expensive and not always permanent.

PELLY CROSSING COMMUNITY PROFILE

Pelly Crossing is a community of approximately 125 inhabitants, predominantly Indian, as approximately 95 percent of the population belongs to the Selkirk Indian Band. It is situated 280 kilometres by highway north of the territorial capital of Whitehorse (see Figure 1). The community was relocated to this site by the Department of Indian Affairs with the opening of the Klondike Highway, approximately 30 years ago. Prior to that time, the traditional community of the Selkirk Indians was at Fort Selkirk which is located at the confluence of the Yukon and Pelly rivers and 50 kilometres west of Pelly Crossing.

Pelly Crossing has an economy based on traditional activities of hunting, trapping and fishing. While these activities provide the Band members with a subsistence lifestyle and seasonal employment, the community's industrial base is severely limited resulting in very high unemployment.

Education levels are low and social problems associated with chronic alcoholism, which plague many northern native communities, are rampart. Few government programs and community facilities are available in the community to alleviate the social and economic disparity.

In 1969, a forest fire swept through the mid Yukon. As a result, Pelly Crossing is accessible to a large firekill area which can support a wood chipping industry.

PELLY CROSSING SCHOOL DESIGN

In 1967, the Department of Education brought two portable trailers into the community to serve, on an experimental basis, as a school offering grades one to nine. Prompted by the success of the experiment, in 1980 the Government contracted an architectural firm, Douglas J. Cardinal Architect Limited, to design the school facility. Based on the wishes of the community, the Government instructed the Architect that the building be appropriately designed to also serve as a community recreational facility accommodating a number of activities such as adult education, sports and recreation. In compliance with the community's specifications, Douglas J. Cardinal Architect Limited designed the $2 million structure. The building is 1,300 m² in size and, in general, is a slab on grade construction.

The design included several energy conservation features. Higher levels of insulation were used in the roof (RSI 9.1) and the walls (RSI 3.5). Approximately 60 windows, designed to face southeast and southwest, were installed with triple glazing. The exterior lighting is of sodium lamps controlled by a photocell. It was also recommended that the classroom lighting be placed parallel to the windows and that the bank of lamps nearest the window also be controlled by a photocell such that they are switched out when not required.

Setback thermostats were installed for programming temperatures in relation to peak and low occupancy rates. It was suggested that a programmable time clock rather than a seven day clock be installed. In this way, holidays and seasonal closures can all be programmed from the beginning of each school year.

The Cardinal design was approved by the Government of Yukon in March, 1982 and tendering was put out in the same month. The contract was awarded to Klondike Enterprises with mechanical sub-contracting to M & R Mechanical; both companies are located in Whitehorse.

To determine the heating requirements for the school, it was estimated that a space temperature of 21°C was required during normal occupancy (50 hours per week) by 50 persons. A setback temperature of 13°C was planned for a duration of 70 hours per week. Night occupancy was estimated to be three persons.

The net heat requirement for the school was estimated to be 11,275 litres of fuel oil or 255.1 gigajoules (GJ) based on the following annual totals:

Heat Loss	608.8 GJ
Solar Gain (20.8 percent)	126.4 GJ
Internal Gain	340.7 GJ

The school was estimated to have an air change rate of .24 per hour.

Originally, it was planned to heat the school with two oil-fired furnaces; however, through the CREDA demonstration project, these were substituted with a wood chipped fuelled boiler supplying the school's space and domestic water heating. The wood chips are supplied by the Selkirk Indian Band from the large firekill area located near the community.

DESCRIPTION OF WOOD CHIP FURNACE EQUIPMENT

Wood energy fuels can be burned in a wide range of combustion equipment. The type of equipment best suited for a particular application depends upon several factors: the type and form of fuel, the heating medium, the heating capacity, the heating output required, economic considerations and convenience for use. Two basic types of combustion equipment are stokers and gravity-fed preheaters; these are described below.

Wood chip stokers consist of a hopper to store the chips, an electric motor-driven screw conveyor (or auger) to mechanically transport chips from the hopper and a combustion grate on which to burn the chips. In addition, the stoker will have some mechanism to ensure that the chips flow down to the bottom of the hopper, a back-fire prevention device and the necessary controls to ensure proper operation. Most stokers also have a blower to provide turbulent, high velocity combustion air. There are overfeed and underfeed stokers. Once the chips reach the combustion chamber, they may drop onto a grate where they burn or, alternatively, the chips may be fed under the fire where they are pushed up into the fire by subsequent chips.

Wood chip burning preheaters have a chip storage hopper located directly above a firebox grate. Thus, the chips are fed by gravity to the firebox. A combustion arch of cast stainless steel or ceramic is located just above the combustion grate in the firebox. Air inlet ducts, a thermostatic draft regulator and an insulated, refractory tunnel leading from the preheater to the furnace or boiler combustion chamber complete the preheater. Some preheaters have mechanical controls and operate without electricity while others have electrically controlled dampers.

Both systems are evaluated in a report, Wood Chip Heating of Homes and Other Small Buildings (Energy, Mines and Resources Canada: 1982); the results are outlined as follows:

	PREHEATERS	STOKERS
Advantages:	- somewhat lower initial cost - no electricity required for operation	- ability to burn dry or wet chips - readily adjustable heat output rates to match requirements - fuel thermostatic control as with oil and gas fuelled equipment - efficient operation - relatively low fuel consumption - infrequent attention - very safe
Disadvantages:	- require more manual tending - relatively high fuel consumption - relatively high minimum heat output may overheat some buildings in fall and spring months - require wet chips - leaks in the hopper or carelessness in closing the hopper may cause a fire hazard	- relatively expensive - require connection to an electricity supply

Through the CREDA Agreement, $90,000 was allocated along with $28,340 from the Department of Education towards the purchase and installation of a wood chip furnace to provide space and domestic water heating for the school. In the Agreement, the demonstration project is described as follows:

> To replace two Bryan CL150 oil fired boilers in the plans for the school with one Vyncke WW3005 wood chip fired boiler complete with automative underfeed system and storage silo, with back up provided by a Bryan CL-90 propane fired boiler.
>
> The incremental cost of the wood chip system is $83,500 with anticipated annual oil savings of $11,635. Therefore the simple payback period is 7.2 years.
>
> Vyncke will provide training in the operation of the system and a local businessman is already trained in servicing the unit.

The Vynke WW3005 is a wood chip fuelled, automatically stoked, underfeed heating system. It consists of a stoker and a heat exchanger connected to a boiler. The fire is located inside the combustion chamber of the furnace and is controlled in much the same way as is an oil or gas fuelled heating system. When heat is needed, a thermostatic control starts the stoker motor to feed fuel to the fire and a hot fire develops. Once the heating requirements are met, the thermostat shuts off the stoker and the fire dies down quickly. Since some time may pass before heat is again required, a time-clock driver control turns the stoker on briefly at regular intervals to maintain a smoldering fire. Use of heavy refractory and insulation materials allows for prolonged low fire sequence which is essential when no heat is needed. During low fire operation, the system functions on natural draft, with only a very small electrical demand required to occasionally activate the fuel feeding system.

The stoker is fitted with a blower connected to the combustion section. This ensures a proper air supply and mixing for complete combustion. The blower is wired into the electrical circuit so that it operates in sequence with the stoker motor. Air is blown through the inlets in such a way that it is directed inwards towards the fuel from around the perimeter of the fire bowl. The air flow blows ashes off the fuel pile in the bowl but is not forceful enough to remove burning chips. The incoming air also serves to cool the upper portion of the combustion bowl where the heat is the greatest. This helps to protect the metal of the bowl.

A control system provides the mechanical means to adjust fuel air ratio. Since biomass fuels are not consistent in nature, compensating control is required to maintain efficient firing at all times. All the motor drives in the system are interconnected with the control system, therefore fuel feeding for both high and low fire is time-controlled and the flow of fuel to the combustion process is regulated in accordance with the required amount of heat. In the event of motor failure, the entire system will be automatically shut down.

Ash is removed from the hearth through the induced draught fan and it is collected in a cyclone on the exhaust flue pipe. The combustion is nearly 100 percent complete so that no creosote deposits are formed on the flue pipes, even though the exhaust gases leave the boiler at relatively cool temperature of about 150°C.

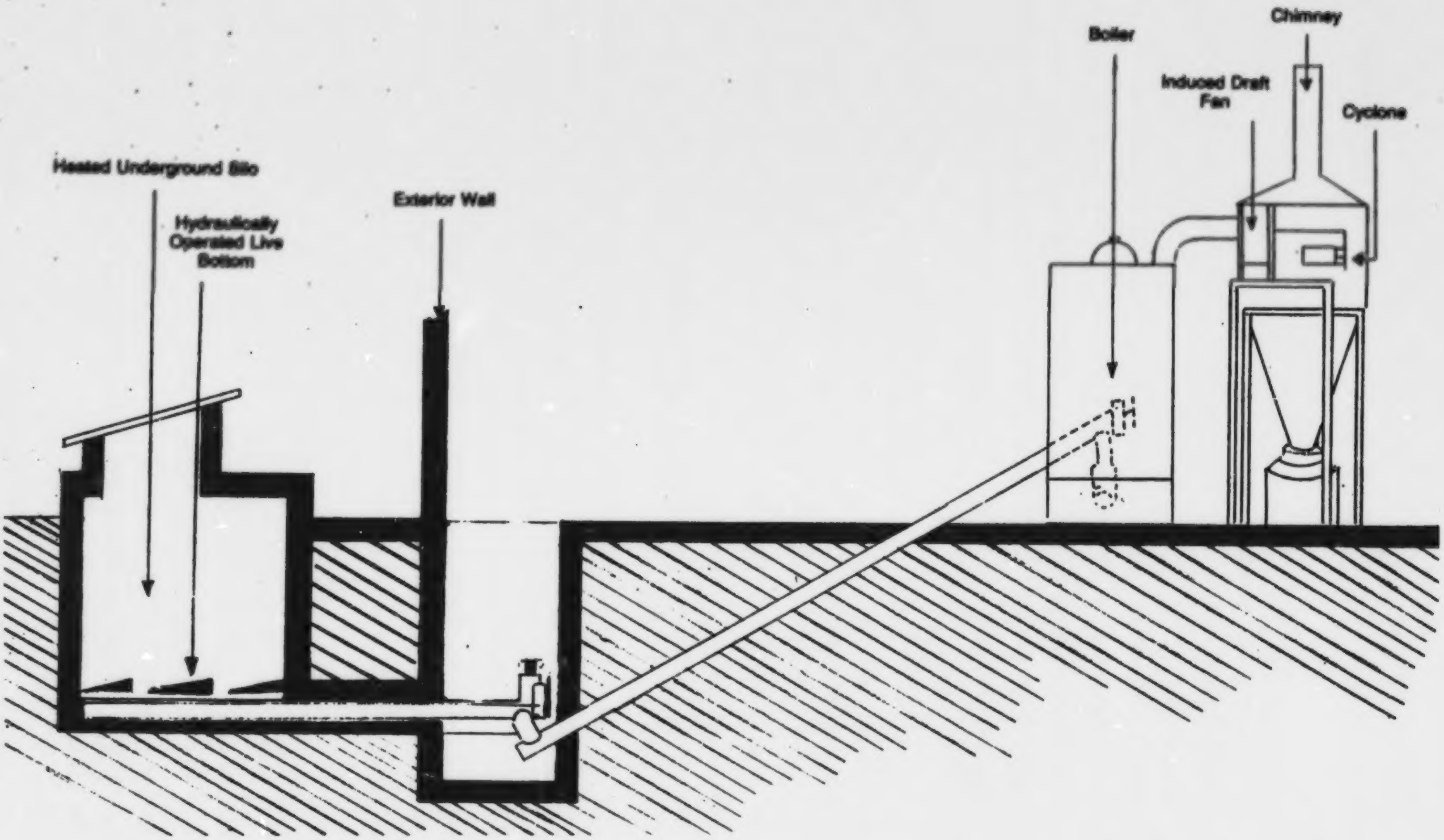
Operation and maintenance of the wood chip burning equipment is simple and requires little of the operator's time. Because the fire quickly dies down when the stoker is turned off, shut down times for maintenance are usually short with no interruption to building heat. The equipment generally is reliable and when breakdowns do occur, repairs usually can be made by the operator to at least restore heat. In case of malfunction with the underfeed system, chips or cordwood can be manually fed into the front loading boiler.

One drawback to these systems is the amount of space required for the storage of the wood chips and the equipment. Usually wood fuelled systems require more space than required for systems using more concentrated fuels. The space required depends upon the heat requirement of the building, the frequency of fuel delivery and the form in which the fuel is delivered.

The storage area for the wood chips may be located either inside the building next to the boiler or outside and transported to the combustion chamber by a mechanical system of augers. Past experiences, often expensive experiences, have taught wood burners to utilize the most effective and maintenance free methods of handling wood biomass.

The Pelly Crossing school wood chip feed system is diagrammed in Figure 2. It was necessary to install an underground heated chip silo (approximately 50 m^3 in size) and a series of underground mechanical silo augers to maintain the architectural harmony of the building. The choice of this particular equipment and design was based solely on suitability to size of the school, heating requirements and the financial allowance.

Figure 2 Wood Chip Feed System


Heated Underground Silo
Hydraulically Operated Live Bottom
Exterior Wall
Boiler
Induced Draft Fan
Chimney
Cyclone

Below grade silos have several advantages over silos built above ground; these include:

1. eliminates any chances of frost in the fuel,
2. fuel stored during warm months will be kept cool for added fire protection,
3. ease of truck unloading as any type of vehicle can deposit in the silo via either an inner ramp or drive-over arrangement,
4. no operators are needed for fuel truck unloading, and
5. power consumption and mechanical apparatus for elaborate unloading systems are not required.

The silo is equipped with a hydraulically-operated live bottom consisting of scrapes or pusher bars. These scrapes move hydraulically through a given stroke. The forward action moves the fuel forward in the bin by reason of vertical front edges of the bar flights. The reverse action of the cylinder forces the sloped back edge of the bar flights under the stored fuel. These scrapes move in opposition to one another, never exerting a constant pressure on the front wall. When in operation, the scrapes will move only under pre-set pressure. If obstructions occur in the silo such as large frozen lumps, the resistance to motion will transfer force to an opposing scrape until the problem is overcome. Chunks of solid wood will find their way out and will surface at the feedout screw.

The fuel is moved from the bin to the combustion chamber through a mechanical system of three augers. Chips move along the silo auger and pass through a transfer point into a second underground auger. The transfer point is contained in a small underground space accessible from the outside and above ground. The second auger is cased underground and transports chips up into the boiler room close to the chip burner. At this transfer point, a fire stop is located to prevent fire from burning back along the auger system should a malfunction occur within the combustion chamber. It is equipped with a water quench system, thermostatically controlled to flood the auger and extinguish any fire. A third auger delivers the wood chips to the fire bowl inside the combustion chamber.

WOOD CHIP QUALITY

Fuel chip quality greatly affects the combustion efficiency and operation of a wood burning furnace system. Fuel chip quality is determined by size and size distribution, moisture content, foreign matter content, species, biological degradation and fraction of bark and foliage. The quality of fuel chosen depends upon the characteristics of the burner system.

Well-maintained and properly operated farm tractor-mounted chippers, commonly used to produce fuel chips, are capable of producing uniform chips. Chippers designed with a chip breaker tend to produce even more uniform chips. The breaker splits and fragments the large chips produced by the knives. Chippers are designed to operate at a particular rotational speed, usually 540 rpm for tractor-mounted chippers. Operating at speeds below the design speed, such as when the machine is being overloaded, increases the fraction of oversize chips produced. This is because chip splitting during cutting, and when passing through the breaker, is reduced. An adequately powered chipper will therefore produce more uniform chips than one that is under-powered.

Sharp chipper knives produce better chips using less energy than dull knives. Dull knives produce large chips and slivers by splitting rather than cutting, particularly at the end of a stick being chipped or with small-diameter pieces such as twigs. The pulverizing action of dull knives produces more small particles and dust, especially with very dry, low-density or decayed wood.

The quantity of larger particles that can be tolerated before equipment malfunction is dependent upon equipment design and operating conditions. The slow speed (1 to 10 rpm), large clearance, high torque augers of most stokers have little difficulty with large particles. By comparison, a 10 cm grain auger with nearly the same clearance but turning at 580 rpm jams regularly because of such particles. The grain auger uses a motor of similar power to those on stokers, but since it runs at higher speed, it has less torque. There does seem to be a critical relationship between particle size and auger clearance, also. The grain auger clearance, even though only very slightly less than those in stokers, may be below the critical level.

Very small material for chipping does tend, especially with dull knives, to turn sideways and slip through the knife opening without being cut into short chips. Pieces of twigs up to about 10 cm long appear in the chips under such circumstances.

Moist wood cuts more cleanly and with smaller energy requirement than dry wood. Above approximately 30 per cent moisture content, wood cutting characteristics do not change. Below 30 per cent wood becomes progressively more difficult to cut and more prone to fragmentation. Analysis revealed that Yukon chips have a 10 to 15 percent moisture content and an average energy content of 20 MJ per kg dry fuel. Low moisture content prevents the freezing together of chips in cold weather and also the growth of fungal spores which could present a health hazard.

Higher-density wood tends to resist cutting forces without damage better than softer woods. Decayed or low-density woods tend to fragment more during cutting than the stronger, higher density ones.

Chips near the average size flow well in hoppers and bins, transport easily through properly designed screw augers and burn well in small combustion chambers. Larger particles tend to block flow and sometimes jam augers. Very small particles (wood dust) are dirty and can cause respiratory problems for persons exposed to them. For these reasons, conditions favorable for producing average-sized chips should be maintained.

DESCRIPTION OF THE WOOD CHIPPING OPERATION

Generally, there are five components involved in wood chipping production; these can be categorized into harvesting, transportation and delivery, processing, services to users and business management. When an individual or contractor considers going into the production of fuel chips, each component should be carefully designed based on a number of considerations. Of fundamental importance is to determine as accurately as possible the sales volume required in order to cover operating costs and provide an economically viable business. Two basic principles for a successful business are:

1. Minimize the manual handling of raw material and chips. Production of fuel chips from logging residues and small trees is very labor intensive and it usually pays off to carefully scrutinize the whole operation from stump to consumer to eliminate wasteful procedures and
2. Use available equipment for harvesting, chipping, transportation and storage.

Prior to deciding to operate an industry, it is necessary to first define the consumer groups available. The three major categories of consumers include individual homes, institutions (school, hospitals and public buildings) and utilities and mining (production of heat and/or electricity). The first group of consumers are usually supplied locally, often by the homeowner or a local contractor. In the Yukon, this group of consumers mainly use cordwood supplied by themselves or local contractors.

The second group requires long-term reliable supplies and they need guarantees against interrupted deliveries. Producers for this category are often woodlot owner organizations, larger contractors or industry with its own harvesting, processing and transportation systems. The needs of the consumers in the third category are similar to those in group two except that their needs will be bigger.

In 1983, the Government of Yukon commissioned Marvin Shaffer & Associates Ltd. to undertake a study, Yukon Energy Inventory and Utilization Review. They determined that wood energy markets in the Yukon would consist mainly of small users. This applies to all of the economic sectors with the exception of possible major industrial and institutional consumers. This fact restricts the size of the potential wood energy industry because it will be more difficult to convince large numbers of small oil and electrical heat energy consumers to convert to wood energy use. Their findings regarding wood and wood waste as an energy source included the following facts:

1. Almost one-fifth of residential space heating energy requirements are currently provided by wood and this promotion will grow over time.

2. Beside the Pelly demonstration project, the Cattermole Timber sawmill at Watson Lake includes a chip-fired steam plant. The possibility of supplying the nearby community with power and heat is being considered.

3. The wood supply for domestic heaters in Yukon is based primarily on firekill timber areas near communities.

4. Other major potential uses of wood as an energy source include the production of power and heat from wood gasifiers, steam plants or burners of various types.

Another consideration is seasonal factors which affect both the supply and demand aspects of the wood energy industry. For the chip producer, winter conditions greatly affect chipping operations and extreme conditions, such as those experienced in the North, substantially increase machine maintenance requirements and down-time. Harvesting and delivery operations are weather dependent and, in Yukon, these operations can be shut down during extremely cold temperatures.

The harvesting systems, methods and machinery chosen also depend on the market price of the wood chips, the storage location and facilities and the volume of chips required. Neill and Gunter Ltd. compiled a Feasibility Study for a Model Wood Energy Industry for Energy, Mines and Resources Canada (1983) which evaluates the economic feasibility of several models of chipping businesses.

The business models included a wood chip supply business, a sawmill residue supply business, a dried wood chip supply business, a wood pellet supply business and a fuel wood supply business.

The financial analysis was based upon a set of principle assumptions which allowed a wage rate for the operating personnel in the models set at $8 per hour plus 20 percent for statutory payroll costs and fringe benefits. The raw material harvesting and transportation operations were contracted out.

The results of the analysis indicated that the purchasing, transporting and handling of the wood energy fuel are the major cost factors in all of the business models. In the most profitable models, the second and fourth models, these costs made up about 50 percent of the total operating costs while in the less attractive cases, they ranged from 62 to 86 percent of the total costs. These costs are also the least controllable of all the factors.

Through the CREDA program, the Selkirk Indian Band was allocated $65,000 for the purchase of equipment to supply wood chips to the Pelly Crossing school. The Band's contribution was in the form of equity in equipment and tools. The summary proposal contained within the Agreement outlines the demonstration project as follows:

> To acquire a small, trailer mounted wood chipper and wood chip storage bin to provide a wood chip supply for the Pelly school. The Band will contribute the truck and miscellaneous tools, (chain saws, axes, etc.) for the operation. Training of Band members in the operation and maintenance of the wood chipper is also to be provided.
>
> In addition, the Band will replace two oil fired boilers in two of their buildings with manual feed wood chip furnaces. Net annual oil savings worth $3,680 at today's prices, are anticipated. Thus a simple payback on these two furnaces of 7 years.

Commitments to be fulfilled by the Band included purchasing the chipper, installing two wood chip burning boilers in Band owned buildings, constructing a chip storage silo and participating in a training program. The training program is outlined as follows in the Agreement:

a) a reconnaissance visit to Fort Providence, NWT for one Band member to become acquainted with the wood chip harvesting methods used in supplying the wood gasifier located at the Snowshoe Inn.

b) a visit to Pelly Crossing of a representative of the manufacturer of the wood chipper to acquaint the chipper operators with the proper maintenance and safety aspects of the chipper's operation.

In September, 1982, the Band was informed by the Government of Yukon that tenders were received for the tractor and chipper. The low bids totalled $36,028 and included delivery and training of two days by a representative from each of BDR Machinery and Cedarbrae Equipment Ltd. There was little money left over to fulfill the other terms of the Agreement. As a result, the order to purchase the two oil fired boilers for the Band was cancelled and an abandoned cabin was fixed up for storage facilities instead of building a new shed. In this manner, the wood chipping operation became dependent solely upon one consumer, the Pelly Crossing school.

The sale price and conditions for the purchasing of the wood chips was established under an Agreement between the Selkirk Indian Band and the Minister of Education, Government of Yukon. The Agreement covers the period during the opening of the new school to the end of March 31, 1984. The terms are set out as follows:

1. The Band shall be responsible for keeping the concrete wood-feed silo at the Pelly school filled above the one-third level with good quality dry wood chips. At each filling the volume of chips delivered shall be measured by a representative of the Band and verified by the school Principal or his/her appointee. Failure to deliver the wood chips as needed may result in a cancellation of this agreement.

2. The Minister agrees to pay the Band a price for wood chips which is equivalent to seventy-five percent (75%) of the residential price of P-30 fuel oil f.o.b. Pelly Crossing, not including any federal or territorial sales tax. For the purpose of this Agreement, fourteen cubic metres (14 m^3) of wood chips shall be considered to deliver the same net quantity of heat as one thousand litres of P-30 fuel oil; and the price of P-30 fuel oil shall be adjusted each September 15 and January 15. Payment will be made upon receipt of invoice specifying date, quantity and price of wood chips delivered.

Recognizing the need for funds to cover maintenance costs for the chipping equipment, the terms of the Agreement established a maintenance fund to operate in the following manner:

> Set up a maintenance fund to be managed jointly by the Band and a representative of the Council for Yukon Indians. At least one third of the payment for wood chips from the Yukon Government of Education is to go directly into this fund, which will be used to keep all wood chip harvesting equipment in good working condition. This fund is to be in effect until March 31, 1984 after which time its balance becomes the discretionary property of the Band.

This condition involved the Council for Yukon Indians in the management of the otherwise Band operated business enterprise. The Council for Yukon Indians is a central organization established to serve the needs of 12 Yukon Indian Bands which formed the association to negotiate their Aboriginal Land Claims in Yukon. In a separate "Wood Chip Production Equipment Maintenance Agreement," the fund was established as follows:

> Money for the maintenance fund will come directly from the sum of at least one third of the payment for the wood chips sold to the Department of Education for use in the Pelly Crossing school. These funds will be deposited directly into the maintenance fund according to the conditions of the agreement between the Band and the Yukon Department of Education concerning the sale/purchase of wood chips.
>
> This Agreement is to endure until March 31, 1984 after which date the balance of the maintenance fund will become the discretionary property of the Band. Prior to release of the fund an audited statement of contributions and disbursements from the fund will be submitted to the Government of Yukon, Conservation and Renewable Energy Demonstration Program. The audit is to be carried out by a certified chartered accountant and paid for out of the maintenance fund.

The equipment purchased to provide chips for the Pelly Crossing school heating unit included a Bruks MTH922 Wood Chipper and to power the chipper, a 40 Hp John Deere 1040 diesel tractor. Specifications for the chipper and tractor are listed below:

Specifications: John Deere 1040 Tractor

PTO Horsepower (max. factory observed at 2500 engine rpm)	44 (33 kW)
Engine	Valve-in-head, wet sleeve variable-speed diesel
Type	3-cylinder
Compression Ratio	16.8:1
Operating range	1400-2500 rpm
Displacement	2940 cm^3
Fuel tank capacity	78 litres
Cooling system capacity	10.5 litres
Transmission	Collar-shift, 8 forward, 4 reverse
Brakes	Hydraulically actuated wet-disk type, self-adjusting, self-equalizing, foot-operated individually or simultaneous
Hydraulic system	Closed-centre
Steering	Power
Differential Lock	Regular equipment, can be engaged under load on the go
Power takeoff	Standard Live PTO 540 rpm
Optional PTO	No
Dimensions:	
Length (Wheelbase)	2.05 m
Hood height	1.4 m
Rear Tread Width (min.)	1.4 m
Front axle clearance (max.)	533 mm
Front tires	7.50-16
Rear tires	14.9-28 (R-1)
Optional	
Front tires	27/9.50-15 (I-1)
Rear tires	16.9-24 (R-3) 21.5-16.1 (R-3)

Roll-Over Safety Frame	Optional
Approximately Shipping Weight	2097 kg
Turning radius (w/brakes)	3.3 m 3.0 m

Specifications: Bruks 722 MTH Wood Chipper

Adjustable length of fuel chips: 6 to 12 mm

Feed opening: 240 x 200 mm

Maximum recommended log diameter: 18 cm

Power requirement for 6 mm chips: 43 Hp (average 10 cm logs continuously)

PTO speed: 540 RPM

Capacity: 16 CBM chips per hour (approximately three cords)

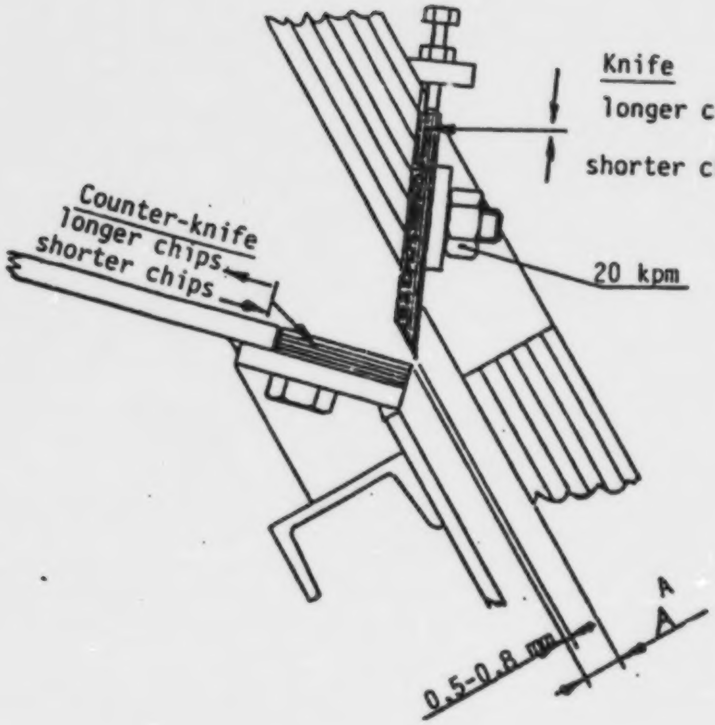
Weight: 700 kgs

Service requirements: knives (two sets last about one year)
anvil (one per year)
drivebelts and filters

This machine has been tested and approved by the Swedish Occupational Safety Board according to its present regulations. The chipper is portable and designed to be mounted directly on the hydraulic lift arms of the tractor. The power take-off of the tractor is used as the power source for the chipper. The power take-off shaft should rotate at 540 rpm and should produce at least 35 HP.

The chipper disc is equipped with four knives. The knives are adjustable and designed for a chip length from 6 mm to 12 mm. Chip length adjustments are accomplished by adjusting the knives and the counter-knife. The knife bolts are torqued to 20 kpm. The distance between knife edges and counter-knife should be set at 0.5 to 0.8 mm regardless of the chip length desired, and knives and counter-knife must be paralled to each other.

FIGURE 3 Chipper Blade Alignment


Knife
longer chips
shorter chips
Counter-knife
longer chips
shorter chips
20 kpm
A
0.5-0.8 mm

Chip length	A
12 mm	8.5 mm
9 mm	6.5 mm
6 mm	4.0 mm

The infeed consists of a stationary lower and a movable upper infeed unit. Both the upper and lower infeed units have rollers driven by chains from a transmission. This transmission is driven by a hydraulic motor. The speed of the infeed rollers is stageless adjusted by a flow regulator.

Set chip length	Adjustment of the flow regulator
12 mm	Dial screwed all the way in
9 mm	Dial screwed out half a turn
6 mm	Dial screwed out a full turn

The chipper disc has four fan blades which transport the chips to the build-in fan. This fan has two functions: it breaks the chips into appropriate size chips and blows them out through the chip transport tube. The chips can be transported to a height of seven metres with an extended chip tube. The fan is driven by V-belts from a pulley on the main shaft of the chipper. This drive includes an automatic belt tension device. Diminishing fan capacity is mostly caused by faulty belt tension due to faulty adjustment of the tension device, or worn out V-belts.

The chipper is equipped with a hydraulic system so that the hydraulic system of the tractor does not have to be used. The three-way direction valve for forward, stop, and reverse can be operated from both sides of the infeed hopper. The stop position is especially useful if one has a less powerful tractor or when chipping harder wood, so that the tractor engine can speed up to full rpm when needed.

The valve has a built-in by-pass valve set at 120 kp/cm². The hydraulic motor must not be exposed to higher pressure. The normal pressure requirement is about 60 kp/cm² but more is needed when the upper infeed unit has to climb up over thick wood pieces or has to compress branches. The pressure compensating flow regulator assures constant infeed unit speed even at varying load conditions.

PERFORMANCE REVIEW

The performance of the wood chip heating system when operational is exemplary. The automatic underfeed system and thermostatic control eliminate the need for monitoring, requiring only an initial lighting of chips in the boiler. The boiler's feed rate and air intake can be adjusted to provide a proper mix for efficient combustion and to supply sufficient heat to the building without being oversized.

Unfortunately, the system's history has not displayed such optimism. The operation of the wood chip system has not been consistent. This inconsistency has created bitter feelings in a number of areas and discredited the system's reliability. Partial explanation for these negative attitudes may stem from initial opposition to the system's installation.

Due to delays in both the school's design plan and plans for the wood chip heating system, there was a state of confusion surrounding the system. On account of this and the fact that the system's installation required modification of an already delayed design plan and incurred a substantial incremental cost, the Departments of Public Works and Education were understandably less than enthusiastic about the proposal. This attitude was somewhat altered once the operation and benefits of the system were explained. Reassured that the school would be adequately heated at all times and that wood chips could effectively halve heating costs, the Government Departments gave their approval for the system's installation. The later inconsistent operation of the system, however, confirmed the departments' earlier doubts. As a result, a certain lack of communication has existed between the participant Departments concerning the wood chip project.

The Selkirk Band held similar reservations about the wood chip system. The concern in their case centred on the type of fuel used in the system. Members of the Band had difficulty accepting the idea of using wood chips rather than cordwood. Many homes in the community are heated by wood, so residents are accustomed to hauling cordwood each year from a designated wood cutting lot.

The wood system seemed unnecessarily complicated. Some members felt that a cordwood heating system should be installed similar to the one installed in the school in Old Crow, Yukon. Here again, attitudes were altered once the benefits of the wood chip system were explained but it was largely the promise of local employment that motivated the Band to accept the idea. The band's initial keenness diminished when the system's operation proved inconsistent. While their interests were more involved in the actual wood chipping, some Band members came to express a sentiment shared by the Departments of Public Works and Education - that the wood chip system should be replaced by a conventional oil system.

There have definitely been problems with the wood chip heating system causing frequent breakdowns and requiring the use of the propane back-up, but these problems do not label the system a failure. One must consider the innovative nature of the wood chip system and as with any innovation, expect initial operating complications. These complications have taken various forms as will be discussed in more detail; however, it may be said at this point that the major obstacle to successful operation appears to be the quality of chips fed to the system. Although there are exceptions, the poor quality of chips has been responsible for the numerous blockages in the auger system and transfer points that have prevented the system from operating to its full potential.

A. WOOD CHIP HEATING SYSTEM

To obtain information on the operating characteristics and energy consumption of the Vyncke boiler, the following meters were to be installed:

1. A BTU flow meter to measure the total heat output of the wood chip boiler,
2. A kilowatt hour meter to measure the electrical consumption of the wood chip feed mechanism and forced draught blowers,
3. A gas meter to monitor the propane used by the back up heating system and
4. A water flow meter to check the amount of domestic hot water produced by the wood chip boiler.

Records of wood chip consumption were also to be kept. Unfortunately, the above meters were not installed; therefore, an evaluation of the performance of the system is restricted only to a discussion of the problems encountered in the first year of operation.

Chip Blockages in the Auger System

The wood chip heating system underwent a trial run in December, 1982; at which time, boiler adjustments were made. No problems with the system were noted. The primary auger drive motor was set at 5.0 RPM. This setting has since been lowered to 2.5 RPM as this rate has been found to supply the combustion grate with the correct amount of chips. The drive motors of the inclined and boiler augers have been set at successively higher rates to prevent chip jamming.

Students and staff took occupancy of the school on March 1, 1983. It was soon after that chip blockages in the augers became a regular occurrence. Investigation showed blockages occuring at the first transfer point, where chips dropped through an opening connected by a flexible corrugated sleeve into a second, inclined auger. Upon closer inspection, it appeared that oversize chips or splinters had fed through the primary auger with little incident but bridged the gap of the flexible sleeve. This bridge caused chips to build up back through the opening and into the auger system as the auger was still supplying chips. Eventually, the continuous jamming caused the auger to be deformed by the force of the chips before it came to a stop. To prevent damage to the drive motor, a slip clutch was installed. However, because of the damage that had already been done to the auger, chips would not feed properly and jams were inevitable.

An inspection in October, 1983 revealed that the chips jamming in the auger itself was the cause of the blockage. The auger was emptied of chips by means of running it forward and reverse for approximately 25 cycles. At that point, hand screened uniform chips of about 10 x 10 x 4 mm were introduced into the auger from the feed silo. The jamming of these perfect chips within the first five minutes confirmed the suspicion that a damaged auger was responsible for the jams. The auger was removed to determine the extent of the damage. About one and a half turns of the auger blade at the downstream end was disengaged from the shaft, causing the pitch to decrease from its normal 150 mm to 80 mm for the last turn. The chips were caught by the constriction and would turn with the auger instead of continuing their forward motion causing chips to bind in the feed tube upstream from the constriction until the friction brought the auger to a halt. The auger was taken to Whitehorse where the damaged flights were welded back to their original positions. The auger was reinstalled and operated without complication until January, 1984.

At this time, the spline connecting the two parts of the primary auger broke. This part was removed and sent to Whitehorse for replacement. The system was still operable with only one part of the primary auger. Adjustments to the slip clutch are believed to be at fault for the spline's breakage. Again, the torque was set too high causing auger damage when jams occur. It is important to keep the torque of the primary drive motor set at minimum.

The bridging problem at the first transfer point was temporarily solved by removing the flexible sleeve and dislodging the splinters by hand. As well as being temporary, this solution was inconvenient for it involved climbing into a cramped, underground access. A more permanent solution was adopted in

December, 1983, when the flexible sleeve was replaced with an angled sleeve (metal on three sides with a plexiglass front). There have not been any bridging problems with the new sleeve.

Chip jams still occur during the normal operation of the system, but the cause of these has been determined as oversize chips bridging in the auger system. The feed system is designed to take chips approximately one centimetre in size. Some chips found in the feed silo have measured as much as eight centimetres in length and three centimetres in thickness. The auger system is simply incapable of handling chips this size. In addition, foreign materials such as rocks and bones have been found in the chip supply and introduced into the system.

There are some considerations to be noted when examining problems associated with the feed auger system. First is the particular lay-out of the wood chip system. The described problems likely would not have happened had there been a direct feed system or hopper supplying chips to the boiler. This would have required a different location of the boiler room. Rather than the front of the school, a better location in terms of chip supply would have been the rear of the school.

The impracticability of changing the boiler room's location leaves no option but to deal with problems as they arise. Several parties have labelled difficulties with the auger system as design problems and suggested larger augers. However, until the correct size of chips are a constant supply, the conclusion has no validity. If blockages still occur with the specified size chips, modifications to the design can be discussed.

A second consideration is the demands created by maintenance needs. In cases of minor chip blockages, it is either the school's principal, or more often the custodian, who must remedy the situation. As a result of the time this requires, the custodian's hours have been increased. The custodian's attentiveness has minimized the need for outside help.

When major blockages occur, it is necessary to dispatch Government of Yukon maintenance personnel from either Whitehorse or Stewart Crossing, each involving a significant travelling distance. In addition, any replacement parts or services have to be supplied from either Whitehorse or often from an outside centre. Consequently, a substantial amount of time is lost in handling before each problem can be repaired.

A reduction of these demands could be achieved with further training of available personnel in Pelly Crossing. Although the boiler's manufacturer has given two demonstrations, these have not proved adequate. A more thorough familiarization with the system by more than one person could facilitate troubleshooting and allow a smoother operation of the wood chip system.

Fan Exhaust System

Another problem associated with the operation of the boiler in the school was the noise level of the fan exhaust system. The fan system provides a forced draft to the boiler's combustion chamber producing a hot efficient fire with the proper air supply.

It was noted during the boiler inspection in January, 1983, that the noise in the boiler room seemed excessive. This was confirmed in March when classes resumed. The noise level in the elementary classrooms, between which the boiler room is located, was measured to be 25 dB higher than the 35 to 45 dB range specified for schools. There was also a noise problem produced by the live floor mechanism caused by floor vibrations and metallic clicks as the hydraulic pulleys changed direction.

The relocation of the boiler room as suggested in the previous section would have prevented this problem. The noise problem was eventually solved by modifying the fan exhaust system.

It was calculated that chips were fed into the boiler at a rate of approximately 0.48 m^3/h, requiring air at a rate of approximately 170 L/s to burn efficiently. A measurement of flue gas revealed an air volume of 405 L/s.

Further calculations estimated that the maximum air requirement for the maximum feed rate was only 205 L/s. In order to reduce the air volume, the pulleys in the fan system were exchanged. By reversing the positions of the drive pulley and the fan pulley, the fan speed was reduced from 2,240 RPM to 1,390 RPM, reducing the air intake to 250 L/s. This modification both increased the boiler efficiency by reducing excess air supply, while still providing adequate air for combustion at maximum auger feed, and it substantially lowered the noise levels.

A minor problem that does not significantly affect the performance of the boiler is associated with one of the boiler's safety controls. A sensor located just upstream from the exhaust fan measures the flue gas temperature. If the exhaust temperature is too low, the boiler automatically shuts down after 25 minutes of operation. This control is intended to prevent the boiler from filling with chips in the event that the fire goes out, a possibility during initial startup or after a prolonged period of no heat requirement, for example, during a warm weekend in spring. Because the flue gas temperature is often cooler than the minimum setpoint temperature of the flue gas sensor, the boiler occasionally shuts down due to low flue gas temperature and must be reset manually. Fortunately, the thermal storage provided by the 3,000 litres of boiler capacity will carry the school for several hours before backup is required and usually the failure is detected before the automatic changeover to backup is activated.

This problem has been alleviated both by increasing the boiler water temperature setting from 60°C to the manufacturer's recommended setting of 75° C, and by decreasing the excess air. Both have contributed to increasing the flue temperature. At present, the problem is only a minor inconvenience and will be eliminated as soon as a sensor of the proper temperature range can be installed.

Another minor problem also related to the oversized fan system was smoke in the boiler room during periods of boiler shutdown. The flue gas damper had been placed in the shut position to provide maximum friction in the flue and thereby minimize the excess air provided by the high fan setting. When the fan speeds were reduced, the dampers could then be opened allowing a much easier passage for the smoke during shutdown. The increased boiler water temperature also contributes to the natural draft and helps to eliminate smoke in the boiler room. This is no longer considered a problem.

Live Floor Mechanism

Problems with the live floor mechanism in the underground feed silo became evident when it failed to operate under a full load of chips. The silo's chip capacity is approximately 36 m^3, but the hydraulic pistons were not supplying enough power to transport chips more than a metre in height to the primary auger trough. The problem was relieved by increasing the pressure of the hydraulic pulleys.

A problem still remains where chips on the far side of the silo fail to reach the auger trough. Chips have to be piled on the near side in order to be fed into the primary auger.

The installation of a collapsible ladder is planned for the silo which will facilitate any work or inspection required in the silo.

Other Problems

Apart from problems associated with the wood chip boiler system, there have been several mechanical complications with other components of the heating system. These include problems with the boiler pumps, the ventilation system and the domestic water systems.

It is not within the scope of this report to discuss these problems, but they are relevant to the subject for they clarify a valid point. Qualified maintenance personnel are not readily available in remote communities such as Pelly Crossing and personnel or repair parts must be dispatched from Whitehorse or southern centres. These problems have not impaired the operation of the school but they have caused inconvenience and have further damaged the reputation of the heating system.

B. WOOD CHIP PRODUCTION OPERATION

The production of wood chips is the foundation of a wood chip heating system. A constant supply of good quality chips is vital to the efficient operation of the heating unit. The contract for supplying wood chips was originally awarded to the Selkirk Indian Band. The choice of the Band as supplier was complementary to the installation of a wood chip burner in the new school. A local supplier who was ensured an accessible source of chips, would save on transportation and long-distance administration costs. For the Band's part, it reinforced a feeling of community spirit in the opening of a new school and built up hopes that the demonstration project would provide an economically viable business opportunity creating local employment for Band members.

Originally, the Band was very enthusiastic about its role in the wood chip operation and made an effort to produce a prompt supply of chips. However, it soon became evident to the Band that profits would not be great and very little employment would be created because the demand for chips was limited. For example, the first shipment of chips delivered before the school opened in March lasted for the rest of the school year. Maintenance costs for the equipment was high due to cold temperatures.

The potential for the Band to become a future commercial supplier to other consumers who were expected to replicate the demonstration project was also limited. The Management Committee for the CREDA wood chipping program anticipated that the successful demonstration of the Pelly school project would motivate other large-scale energy users to adopt the system and thus create additional markets for wood chips. A major potential customer identified was a rejuvenated central Yukon mining industry. However, new additional markets did not materialize leaving little motivation for the Band to continue to pursue a wood chip industry. The cancellation of the purchase of the two wood chip boilers for installation in Band buildings and the lack of funds to build the storage facilities lead to further disappointment for the Band and lessened the realm of benefits incurring to the Band from the demonstration project. These factors, along with the production of poor quality chips and operating difficulties with the wood chip heating system and chipping equipment, replaced interest with skepticism and a reluctance for further association with the wood chipping operation.

The major problem with the wood chipping operation has been the production of poor quality chips. This refers only to quality of shape, for the chips have a low moisture content and a high energy potential. As described in the previous section, poor quality chips are detrimental to the operation of the wood chip boiler. Poor quality chips resulted primarily from a lack of maintenance to the wood chipper.

Maintenance

The Bruks 722 chipper was chosen on account of its strong showing in other demonstrations. Together with the 40 hp John Deere tractor, it was believed capable of handling the needs of the school's boiler system.

It is very important to keep the chipper properly maintained, especially the anvil, main shaft bearings, fan blades and knives. In particular, close attention must be paid to the knives. The chipper knives must be ground and honed whenever they are suspected dull, noticeable by irregular chip size and heavy working of the infeed unit, where the knives actually push back the material. It is essential that the knife edges be sharpened to the exact required angle, otherwise the blades will chip improperly.

The Bruks chipper was purchased with a sharpener made from a modified drill press produced by the chipper retailer, BDR Machinery of Mississauga, Ontario. The sharpener ensures that the knives are sharpened to the correct cutting edge for even the slightest aberration of two to three millimetres will cause chipping problems. Poor quality chips result, the infeed unit works too hard and the knives quickly become dull again. The BDR sharpener is adequate only for maintenance purposes, not for full-scale blade repair.

The need to sharpen the chipper's blades varies with the type of wood chipped. Generally, the drier the wood, the harder the knives work; and therefore, the higher the frequency needs for sharpening. In Pelly, where the majority of the wood is firekilled and contains little moisture, the knives require frequent sharpening.

Since the August, 1982 delivery of the wood chipper, it is reported that the knives have not been sharpened even a minimum number of times to prevent the production of poor quality chips. Additionally, the distance between the knives and anvil has not been consistently observed, resulting in serious damage and bad chips.

The original set of knives were damaged by faulty anvil adjustment in the fall of 1982 and remained at Pelly in disrepair for over a year. The spare set of knives have, therefore, been in constant use. The damaged original set was eventually sent to Prince George as the damage was too severe for repair in Whitehorse. The damage appeared to result from knives set too close to the anvil causing deep gouges in the cutting edges. It was necessary to shear approximately 10 millimetres from the cutting edges. These knives are still not in use, as they are reported too short for the chipper.

Tractor

The 1040 John Deere diesel supplies the required minimum of 30 kW (40 hp), but it does not supply sufficient power to drive the Bruks chipper when chipping large size wood. The tractor speed decreases considerably when cordwood more than 125 mm in diameter is used. The infeed must be momentarily slowed, allowing the tractor and chipper disc to build momentum before continually feeding. The lack of power is not detrimental, unless combined with a steady feed of large size wood or poor knife-setting/maintenance, in which case poor quality chips are produced.

As mentioned earlier, the tractor was not winterized and could not be started during cold temperatures. The cost to properly winterize a diesel tractor is substantial and the Band did not have sufficient money in the maintenance fund to cover the cost of installing the required electrical heating units in the engine. Winterizing the tractor by no means guarantees that it will start in cold temperatures and it would also be necessary to store the tractor in a building, preferably a heated shop. The Band does not have a facility available for storing the tractor nor for storing the chipper.

This problem will have to be alleviated if the chipping operation is expected to satisfy supply upon demand. Another option would be to build a storage facility for wood chips within the comunity and chip only during mild weather.

Contractor

Although the Selkirk Band was responsible for the maintenance of the chipper, the foreigness of wood chipping and the lack of adequate training have been at fault. As stated earlier, the wood chip operation seemed unnecessarily complicated in comparison to a cordwood system. Augmenting this situation, there was only a brief training package of one day involving a limited number of Band members. Considering the lack of facilities in Pelly Crossing and the relative inexpertise of the Band, designated operators should have been familiarized with large-scale chipping. This could have involved either travelling to a centre where chips are commercially produced, or better, having a chipper representative oversee the first major wood chipping in Pelly. A standard of quality would have been set and any questions or equipment problems solved as they arose.

The first shipment of chips was supplied before the school opened and this amount was sufficient for the remainder of the school year given the sporadic operation of the wood chip boiler. With no demand for wood chips, there was no employment created by the chipper that spring and summer. Understandably, without the expected employment or financial gain, the Band began to lose interest in the wood chip operation. Consequently, when chipping was required in the fall, it was difficult to find operators.

In August, 1983, the Department of Education made an agreement with the Band to purchase eight foot length (2400 mm) cordwood 150 mm in diameter. This wood was piled in the schoolyard and chipped as needed into the feed silo. The terms of payments were $65 per delivered cord and $40 per hour for chipping.

There were problems ensuring an adequate chip supply during the winter months. When the chip supply was depleted, it took as long as two or three days before someone chipped a new supply. At best there are only two or three residents trained to operate the chipper and, if these people were not in the community or not interested, chips were simply not produced. The supply problem was exacerbated as the weather became colder and chipping was further delayed by the tractor failing to start. The tractor had not been winterized.

In January, 1984, the Government of Yukon offered to assume ownership and maintenance of the Bruks chipper from the Selkirk Band, with the belief that chip quality would be more uniform and any major maintenance costs could be better absorbed. The Band, who will remain the supplier of cordwood and whose members will still be hired for chipping, readily agreed since the operation had become an administrative headache and netted the Band little financial gain.

Future recommendations include building a garage to house the chipper and designing a better storage facility. The Band has also suggested opening up the chip contract to bids within the Band and elsewhere.

Chip Contamination

Aside from poor quality chips and splinters, contaminated materials have caused blockages in the auger system. Foreign objects such as rocks and bones have been found in the boiler combustion grate and throughout the feed system.

The chip supply ran a high risk of contamination when the chips had to be stored in an unused cabin because funds were not available to build the storage facility as originally planned. There was no door on this cabin and dogs and children often played there. This storage site is no longer used. Instead wood is presently chipped outside the school directly into to the feed silo.

C. OUTLOOK

The chipper equipment was handed over to the Yukon Government on January 30, 1984. Under the Government's maintenance and administration, a constant supply of high quality chips should be guaranteed, allowing the wood chip heating system to operate efficiently and cost-effectively. An awareness of past pitfalls and implementation of recommendations will further this intention.

BUDGET REVIEW

Table 2 outlines the estimated and actual costs of the Pelly School wood chip furnace system. Approval was granted for a total project cost of $118,340 of which the applicant contributed $28,340 and $90,000 was granted by the CREDA program. The applicant's contribution is indicated on the Table as credits for the oil boiler and propane backup which would have been installed if the demonstration project had not provided funding for the wood chip furnace system.

It should be noted that the items of automatic changeover electrical connection and contractor's markup have been included as actual costs. These expenditures were approved by the Public Works Department with neither the consent of or consultation with the Energy and Mines Branch.

The initial installation of $5,000 was considered the incremental cost of installing the wood boiler over the cost of installing an oil boiler and was never meant to include the full installation cost. Miscellaneous charges approved by Public Works included such items as research into the sources of supply in North America after the Vyncke boiler had been ordered. CREDA contributed its approved $90,000 which included a $6,500 contingency allowance but further contribution to incremental costs beyond this figure could not be justified.

TABLE 2

ESTIMATED AND ACTUAL PROJECT COSTS
WOOD CHIP HEATING SYSTEM

Item	Budget	Actual
Vyncke Model WW3005 (f.o.b. Pelly Crossing)	77,500.00	77,500.00
Warranty	3,000.00	3,000.00
Glycol Heat Loop	4,000.0	4,000.00
Concrete Feed Silo	13,000.00	13,000.00
DHW Heat Exchanger	6,840.00	
Installation	5,000.00	5,000.00
Engineering Redesign	2,500.00	
Contingencies Allowance	6,500.00	
Auto Changeover Boilers		9,975.54
10% Contractor Markup		4,327.14
Install DHW Exchanger		19,226.03
Electrical Connections for Boiler		4,418.76
Enlarge Storage Silo		7,489.00
Misc. Changes		4,684.06
10% Contribution Markup		3,581.00
	118,340.00	156,201.53
Credit for Oil Boiler	-12,000.00	-12,000.00
Credit for Propane Backup	-16,340.00	-16,340.00
	28,340.00	28,340.00
Total	90,000.00	127,861.53

Table 3 outlines the estimated and actual costs of the wood chip production operation. Approval was granted for a total project cost of $65,000.

An additional $15,000 was allocated towards the wood chip demonstration project to cover technology and information transfer programs. Therefore, in total $165,000 was estimated to cover the costs of the demonstration. This is approximately $15,000 less than was actually spent.

TABLE 3

ESTIMATED AND ACTUAL PROJECT COSTS

WOOD CHIPPING OPERATION

Item	Budget	Actual
Bruks 722 Chipper		10,880.00
John Deere 1040 Tractor	20,000.00	17,980.00
Wood Chip Heaters and Installation	25,000.00	
Wood Chip Storage Shed	10,000.00	982.47
Training Program	10,000.00	3,200.00
Freight		2,300.00
Oil and Filters		184.11
Drill Press Sharp		902.00
Spare Knives		266.00
Grinding for Knives		60.00
Miscellaneous		92.20
Total	65,000.00	36,846.78

ECONOMIC ANALYSIS

The cost effectiveness of the Pelly School Wood Chip project must be examined in comparison to the cost of a conventional fuel oil system. In addition, a more reasonable idea of savings can be realized using the life expectancy of the building rather than a simple payback period.

It was estimated tht the Pelly Crossing school requires 480 GJ for space heating and 480 GJ for domestic water supply for a total of 960 GJ annually. This equals 120 kilowatts (kW) to heat the building when occupied and 40 kW to heat it when unoccupied assuming a -45°C outside temperature, a 30 kW heat loss through the walls, roof and windows and a 90 kW heat loss through the ventilation system. Assuming that the building is occupied for approximately 68 hours per week, the heat load requirement would be 12,060 kWh per week.

The original heating system in the school's design plan utilized two Bryan CL150 oil fired burners, which would have cost approximately $40,000 with installation. It was estimated that this heating system could supply the school's heating requirements by using 41,000 litres of fuel oil.

The 350 kW Vyncke boiler was proposed to replace the main oil burner at an incremental cost of $77,500 with an oil backup system costing $31,224. A propane backup later substituted the oil system with a further cost reduction of $16,340. Propane was chosen over oil for a number of reasons: while more expensive per unit of delivered heat than fuel oil, it does not require an underground storage tank, stores well without the problem of paraffin precipitation which can occur in oil during prolonged periods of non use and the initial installation cost is much less expensive.

In calculating the cost effectiveness of the wood chip system in comparison to oil, an efficiency rate of 60 percent was assumed, although 75 to 80 per cent efficiency is a more realistic estimate (similar amounts of wood being two to five percent lower than oil). At a 60 percent efficiency rate and 1982 prices (.40¢ per litre oil and $40 to $50 per cord) the price of delivered heat from oil is $17.44 per GJ and $4.36 per GJ from wood.

The cost for heating the Pelly School for one year with fuel oil was estimated to be $16,740. In comparison, heating the school with wood chips was $4,190. A further estimate calculated incremental maintenance costs to the wood chip system at 40 hours per year or $8,000 plus 700 kWh of electricity costing $120 to power the electric augers. The savings for the first year using wood chip heating was estimated to be $11,630. A savings stream for a 15 year life of the boiler was calculated with the present value of $148,593 at a five percent discount rate and with the price of oil rising at two percent annually. The simple payback period for the wood chip system was an estimated 10.4 years.

Given the operation and maintenance difficulties with the Pelly School system, this payback period cannot be attained. For this reason, cost effectiveness calculated over the lifetime of the building is much more realistic. The expected lifetime of the school is 40 years or more over which the capital and installation costs will be recovered and substantial heating costs saved.

It has not been possible to calculate accurately the cost/benefit savings from the wood chip heating system and chipping production operation. The heating system has not operated at full capacity and the propane system has been used excessively. As well, it was necessary to make changes to the initial agreements which set out the responsibilities and pricing for the wood chipping operation. Maintenance and repair costs were also high both for the chipping equipment, as a result of poor quality chips, and to work the kinks out of the wood chip heating system.

IMPACTS

Wood chip burning systems are described as clean, safe and efficient posing no substantial threat to the environment. Wood chip furnaces burn cleaner than cordwood burning furnaces and eliminate many of the concerns regarding air pollution from cordwood burners. A wood chip fire, given the proper air supply for combustion, burns hot and efficiently and produces few wastes. There is a minimum of smoke and ash expelled through the flue and, consequently, little creosote formation in the chimney. A properly burning wood chip fire does not release significant amounts of sulphur dioxide, as produced by coal or oil burning furnaces, or nitrogen dioxide and nitrous oxide because the temperature at which the chips are burning is usually too low to combine nitrogen with oxygen. If the air is mixed properly in the furnace, there is no problem with carbon monoxide. There is then little risk of a polluting smoke haze similar to the haze experienced in the Riverdale residential area of Whitehorse due to cordwood burning.

The Government of Yukon requested A. Lanfranco and Associates to conduct a series of emission tests on discharges to the atmosphere from the wood fired boiler located at Pelly Crossing. The objectives of the study are to conduct a number of stack emission tests, analyze the samples for various organic/inorganic components, calculate boiler efficiencies and extrapolate emission results in terms of boiler operating levels. The main purpose of the study is to quantify emission characteristics for three different fuels under two operating conditions. The results of the study are included in the Appendix to this report.

There is one health hazard associated with the handling of the wood chips. Chips can produce airborne dust and fungal spores, causing allergies. This effect can be lessened if handlers wear protective masks and clothing. The problem of fungal spores is not expected with the Pelly demonstration because of the dryness of the chips and the location of the silo outside the school.

In terms of the negative side effects wood chipping presents to forests, these would only develop if large scale chipping commenced. Ideally, wood chipping does not compete with the cordwood harvester, for chippers can be fed branches, tree tops and other "unusable" parts. In this manner the whole tree is harvested. However, if cordwood is used, as in Pelly Crossing, there could be a depletion in wood supplies close to population centres. This would demand stricter conservation measures in designating wood cutting areas.

Consequences of large scale wood chipping include possible soil erosion, threats to the wildlife and vegetation populations and damage to soil fertility. The implications of these possibilities have not been investigated at this time, although future developments may warrant attention.

The social impacts of the wood chipping industry are unclear at this time. While the wood chipping operation did affect the lifestyle of the Indian population of Pelly Crossing in terms of employment and income, it is impossible to assess the degree of affect without further research. The timeframe for this report did not allow the necessary time to assess these social impacts. The social impacts of possible land use conflicts and compatibility should also be examined more closely in terms of other land uses, for example, wildlife habitat and agriculture.

The economic impacts are outlined in the previous section, "Economic Analysis."

POTENTIAL FOR REPLICATION

It is estimated that Yukon's annual space and DHW heating requirement are 2.5 petajoules (PJ) and an additional 1.0 PJ for industrial heat supply. This requirement is presently almost wholly dependent upon imported fuel sources. This dependence could be lessened by substituting wood-burning furnaces for oil.

It is assumed that there is 0.9 TJ of bioenergy available from each of the 7,400 hectares of forest killed by fire in Yukon each year. The 3.5 PJ heat requirement could be obtained by harvesting one-half of the firekilled wood. However, much of this wood is inaccessible. Alternatively, there is approximately 750,000 ha of forest in Yukon, a portion of which is readily accessible. The annual 3.5 PJ requirement could be supplied by harvesting 10 per cent of the sustained annual yield of Yukon's forests. These assumptions give an idea of the renewable energy resource potential in Yukon. This potential is presently utilized only by residents using cordwood to heat their homes. While this alternative energy use is progressive, real cost-saving benefits and energy self-sufficiency will not be achieved until commercial enterprises and industry begin to utilize wood heat.

Heating with wood chips offers Yukon industry and business a viable energy alternative because inflated northern fuel oil prices consume a substantial portion of profit and unlike southern counterparts, businesses have no access to a cheap supply of alternate energy fuel. It is not practical for businesses to burn cordwood in terms of personhours spent in monitoring a stove but an automatic underfeed wood chip burner eliminates this expense. Considerable heating cost savings can be demonstrated and the wood chip burner is adaptable to any type of heat exchange system providing heat to one or a number of buildings. In addition to heating buildings, wood chip burners can play an important role in Yukon's mining industry, in terms of drying products before transport. Although the industry is presently in a slump, wood chips would be a timely proposal considering the low operating costs and the large fuel supply in the vicinity of most mines.

The possibilities of commercialization with wood chip heating are immense. The expense of heating by oil while there is a vast supply of alternative energy fuel begs for an innovative heating style. The wood chip system offers a reasonable alternative for reasons already discussed.

The Pelly School project has already generated curiosity in a variety of areas. A Whitehorse millwork shop has expressed an interest in purchasing a small wood chip burner. The company has a good supply of wood shavings and sawdust produced by their operation and is presently paying to have these waste materials hauled away. They stand to save costs in two directions and are considering heating nearby buildings by means of district heating systems.

A large Whitehorse hotel, planning to expand, has also expressed an interest in converting the present oil heat system to wood chips.

Two other Yukon Indian Bands are interested in installing wood chip heating systems in their proposed Band complexes. The Dawson Indian Band has completed construction of a new complex which is heated by a cordwood system. In order to reduce maintenance needs and costs, the possibilities of purchasing a chipper and hopper system are being discussed.

The Carmacks Indian Band is planning the construction of a band complex and a small apartment unit. The Band's intention is to use a wood chip heating system in these two buildings as well as a community hall and wash house already completed. Notwithstanding this interest in wood chip heating, there are two barriers which impede its adoption. The first of these barriers is the bad reputation the Pelly School project has generated. The second is the lack of a well-established supplier.

Negative opinions about the performance of the Pelly School heating system have reached a number of audiences and unfortunately most potential targets. The demonstration value of the project has evidently been less than successful. Most observers, however, do not realize the important role that chip quality plays in the system. Hopefully the efficient operation of the system with a future supply of good quality chips will improve the demonstration value of the project and reverse those opinions.

In order to effect this change of opinion, the successful demonstration of another wood chip project is required. A Whitehorse-based demonstration project would be ideal for there would be no complications with long distances or lack of service centres and personnel. The intial bugs encountered with the Pelly project can be anticipated and any problems can be quickly eliminated. The location of a second demonstration in Whitehorse will also ensure a higher profile with Yukon's business community.

The second barrier to be overcome is the lack of a chip supplying industry. There is virtually no logging industry in Yukon so the establishment of a chipping industry presents a substantial risk. Yet without a reliable supply there can be no demand for chips. Potential customers are wary of adopting a system if obtaining fuel may be a problem. This catch-22 situation can be solved only with a successful duplication of the wood chip project thereby providing incentive for replication.

A second wood chip demonstration thus appears to be the solution for future replication and commercialization. However, since the implementation of a second project may take some time, an intensified information and technology transfer plan for the Pelly School project may be required to accomplish the same objective.

CONCLUSION

The Pelly School wood chip project may be described as a relative success. It demonstrated that wood chips may be used as a main space and domestic water heating system in a large structure able to withstand extreme temperatures. Unfortunately, the problems encountered in the initial year of the system's operation could not be solved immediately and therefore, increased the seriousness of the problems. However, given the operating conditions of the project - the relative isolation of the community site and the absence of maintenance services and personnel - it is reasonable to conclude that the demonstration has been a success.

The Pelly School project draws attention to the need for further wood chip demonstration. Interest in this alternative energy source definitely exists in Yukon; however, potential consumers require verification of the system's reliability and cost effectiveness. Recommendations for future wood chip system demonstration include:

- choice of a demonstration site close to maintenance centres and
- the presence of a reliable chip supplier.

The successful visible demonstration of another wood chip project observing the above recommendations would counteract the negative opinions generated by the Pelly project and make possible replication.

EMISSION MONITORING SURVEY OF WOODCHIP BOILER EXHAUSTS
Pelly Crossing, Yukon

Prepared For:

GOVERNMENT OF YUKON
ENERGY AND MINES BRANCH
Whitehorse, Yukon

Prepared By:

A. LANFRANCO AND ASSOCIATES
Langley, B.C.

April, 1985

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SUMMARY

The following table illustrates the quantitative levels of specific parameters for certain boiler fuels and operating conditions.

Fuel/ Condition	Total Emissions*			Volatiles	NO_x	Overall Boiler Efficiency	Particle Size Dp 50
	(mg/m^3)	(mg/m^3 @ 12% CO_2)	(kg/GJ)	%	(mg/m^3)	(%)	(Microns u)
Dry Chips/ Hot Burn (Avg)	72	154	0.078	44	11	88	2.6
Dry Chips/ Slow Burn (Avg)	102	1420	0.751	92	1.9	57	1.4
Cordwood/ Hot Burn	68	123	0.067	46	14	88	-
Cordwood/ Slow Burn	60	402	0.192	87	0.3	78	-
Green Chips/ Hot Burn	61	167	0.118	40	12	81	-
Green Chips/ Slow Burn	280	3362	33.8	97	2.0	6	-

The most commonly occuring hydrocarbons were phenols and cresols, and their relative amounts were greater in the slow fire mode than the hot fire mode.

The only priority pollutant POM's detected in any of the samples were phenantharene/anthracene at a concentration of 0.08 mg/m^3 in Test No. 1, a dry/slow burn, and naphthalene at a concentration of 0.16 mg/m^3 for Test No. 8, a green/slow burn. Any other POM's were either below the detectable limit of the method or not present at all.

The British Columbia provincial guidelines for particulate discharges from combustion sources, which would apply to this process during hot burns, allow particulate concentrations of 230 mg/m^3 @ 12% CO_2. The process would most likely be considered a non-combustion source during slow burns and the guideline would be 230 mg/m^3 (uncorrected for CO_2 concentration). The guidelines consider particulate as the "front-half" catch only. The guidelines do not address nitrogen oxides at present.

The results of these survey tests would be well within the B.C. guidelines and the unit would be considered in compliance if operated in B.C.

Studies of woodstoves (Ref. 5 and 7) have indicated particulate discharge (including condensables) at about 15 to 30 grams of particulate/kilogram of fuel (g/kg) at about 95% combustion efficiency. This survey shows results of about 3 g/kg for hot burns and from 3 to 27 g/kg for slow burns. It is evident from these results that the Pelly Crossing boiler operates at a higher combustion efficiency and emits a lower level of particulate discharge that the woodstoves studies in the reference material.

Although not regulated, nitrogen oxides at the concentrations determined during this study, would be considered by the B.C. Waste Management Branch to have a minimal environmental impact.

* (Particulate and Condensed Extractables)

1.0 INTRODUCTION

The Energy and Mines Branch of the Government of Yukon retained A. Lanfranco and Associates to conduct a series of emission measurements on the exhaust of a woodchip boiler located at Pelly Crossing, Yukon.

The primary purpose of the survey was to quantify levels of air contaminants under varying boiler operating conditions. Parameters investigated were particulates and particle size, nitrogen oxides, oxygen, carbon dioxide, carbon monoxide and hydrocarbons including POM and Non-POM.

An additional goal of the survey was to determine boiler efficiencies and present the relationship between emission levels and useful heat output.

This report documents the methods used and the results found for the survey conducted on 4, 5, 6 and 7 March 1985.

3.0 METHODS

All sampling and analytical methods conform to those accepted by the B.C. Ministry of Environment, US EPA, or the Oregon DEQ.

3.1 Sampling Techniques

Three independent sampling systems were used to collect the various samples. A Napp (Lear Siegler) stack sampling train (Fig 1), modified for hydrocarbon impingement and without a cyclone was used for particulate sampling. An Anderson Mark V in-stack cascade impactor was used for particle size determinations. A caustic-permanganate impinger train equipped with a glass probe, flow controller, pump and dry gas meter was used for NO_x sampling.

All particulate and particle size sampling was conducted isokinetically. A twelve point equal area sampling regime was used for each test. Points were sampled for 5 minutes each on slow burns and 3.5 minutes each on hot burns. Temperature, pressure, moisture, O_2, CO_2, and CO were measured on an integrated basis for each test. Stack gas velocity pressure was measured with a calibrated S-type pitot tube attached to the heated sampling probe. The low velocity pressures associated with the slow burn mode were measured with a high sensitivity oil manometer. Temperatures were measured with a chromel-alumel type thermocouple. Flue gas analysis for O_2, CO_2 and CO was conducted with a Hayes 601 Orsat analyzer from an integrated bag sample collected at the stack. Low CO Orsat readings were confirmed by Draeger tube analysis.

NO_x samples were extracted from the stack at a constant rate of 0.5 L/min into a series of three impingers each containing 100 mL of 4% potassium permanganate in 2% sodium hydroxide.

Grab samples of fuel were collected for moisture and heat value analysis. Fuel feed rates were measured by collecting the auger discharge over a timed period.

2.0 PROCESS DESCRIPTION

The unit tested in this study was a Vyncke WW300S three pass vertical fire tube boiler. The function of the boiler is to provide heat to the Pelly Crossing school.

Heated boiler water is pumped to a water/glycol heat exchanger. The glycol is then pumped throughout the school where heat is released by means of radiators.

Normal boiler fuel is fire killed spruce and some fire killed pine. The fuel is chipped into a holding bin outside the school and fed to the boiler by a series of screw augers. Emissions from firing seasoned cordwood and green woodchips were also investigated in this study.

The boiler operates in two modes which are controlled by a pre-set aquastat. The hot-fire mode operates whenever there is a heat demand, i.e. when the aquastat temperature falls below the set point, and the slow fire or smoldering mode operates when the aquastat temperature is above the set points. During the hot firing only, the chip feed and the exhaust fan run until the upper aquastat limit is achieved. In both modes the boiler exhaust gasses are partially "cleaned" by a cyclonic separator prior to being discharged to the atmosphere through a 25 cm insulated smoke stack.

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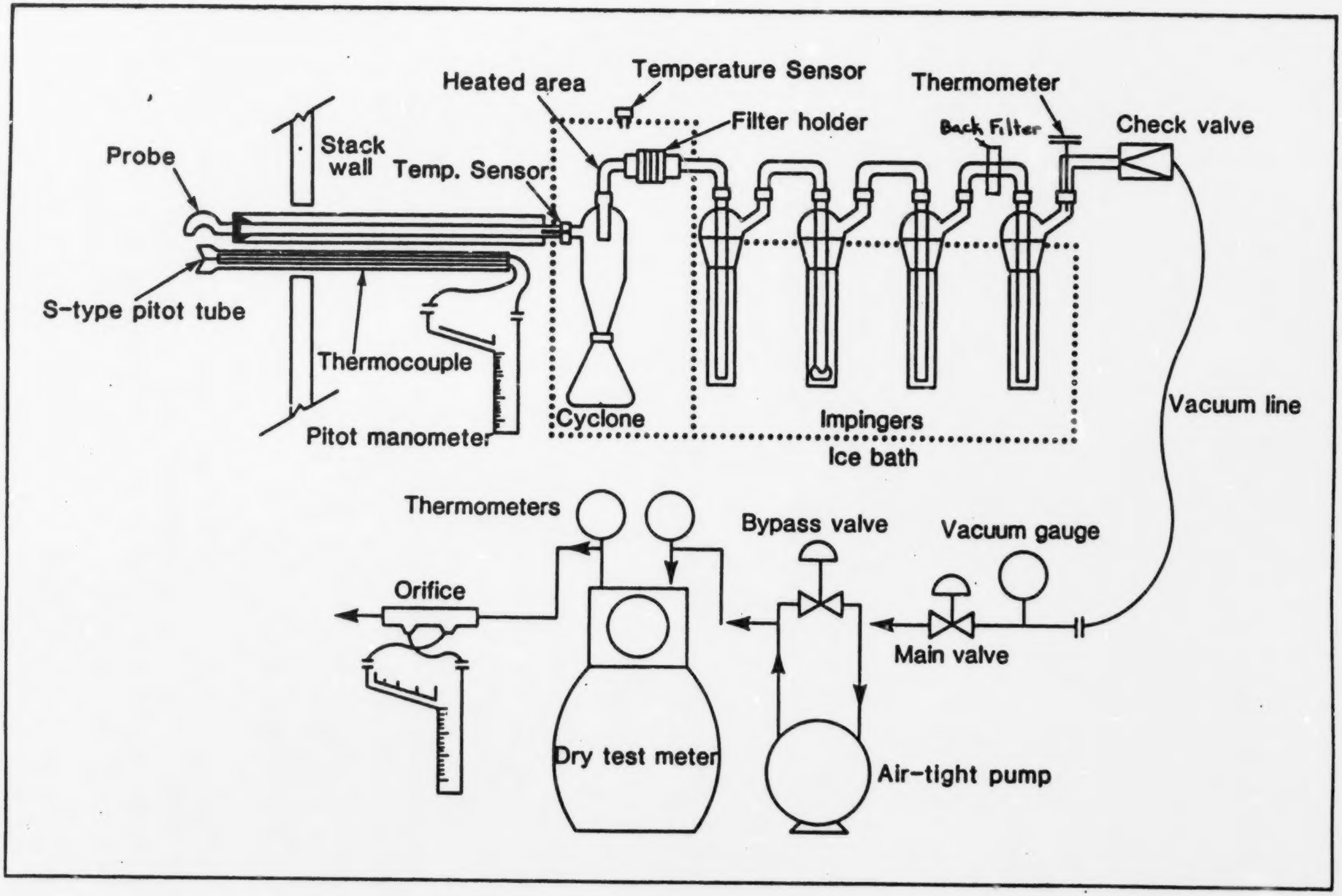


Heated area
Temperature Sensor
Thermometer
Filter holder
Back Filter
Check valve
Probe
Stack wall
Temp. Sensor
S-type pitot tube
Thermocouple
Pitot manometer
Cyclone
Impingers
Ice bath
Vacuum line
Thermometers
Bypass valve
Vacuum gauge
Orifice
Main valve
Dry test meter
Air-tight pump

Figure 1 Particulate Sampling Train

3.2 Analytical Techniques

3.2.1 Sample Clean-up

The necessity to provide hydrocarbon analysis of the particulate samples required special clean-up procedures. The particulate sample consisted of four components: a probe wash and filter which comprised the "front half" of the sampling train; and an impinger solution and a back filter which comprised the "back half" of the train. After sampling the front filter was removed from its holder, placed in an aluminum dish and sealed. The probe, nozzle, and pre-filter glassware were washed with acetone and methylene chloride into clean glass sample bottles and sealed. The impinger waters were measured with a glass graduated cylinder and placed in a glass sample bottle. The impingers and connecting glassware were rinsed with acetone which was added to the impinger water. The back filter was removed from its holder and sealed in an aluminum foil dish.

NO_x samples were washed into polyethylene containers and sealed.

3.2.2 Total Emission Analysis

Gravimetric analysis of the front filters was conducted by dessicating to constant weight and weighing. A known portion of the probe wash was evaporated to dryness and weighed. A known portion of the impinger solution and back filters were extracted with freon. The extracts were evaporated and the residues weighed. The combustible fractions of the front-half of the train was analyzed by igniting a portion of the front filters and dried probe wash residues at 600°C and reweighing. Blanks were carried through all procedures.

3.2.3 Hydrocarbon (HC) Analysis

The unused portions (for total emissions) of each sample component were used for HC analysis. Each component was extracted with methylene chloride and the extracts combined and reduced in volume for gas chromatographic (GC) or GC-mass spectrographic (GC-MS) analysis.

Six sample extracts were preliminarily screened using a Hewlett-Packard 5890 GC equipped with a FID detector. A capillary column, 25 m x 0.32 mm/ID 5% phenyl methyl silicon, and helium carrier gas were utilized.

The complex nature of the samples necessitated further examination by GC-MS methodology. The GC-MS technique is one with greater sensitivity and applicability than straight GC analysis. Two of the more complicated samples underwent GC-MS scrutiny with resultant identification and quantification of POM/non-POM compounds. The quantification of POM/non POM compounds in the other four samples was conducted by peak area comparisons for compounds identified by the GC-MS runs. Again, blanks were carried through all procedures.

3.2.4 Nitrogen Oxides (NO_x) Analysis

Nitrogen oxides, expressed as nitrogen dioxide, were determined using the cadmium reduction plus diazotization method. With this method NO_x are quantitatively converted to nitrate which is subsequently reduced to nitrite and determined by diazotizing with sulfanilamide and coupling with N-(1-napthyl) - ethylene diamine. The coloured solution is measured at 529 nm with the result compared to a series of prepared standards in order to calculate the amount of nitrogen in each sample.

3.2.5 Particle-Size Analysis

The particle size analysis was a gravimetric analysis where material deposited on a series of impaction plates is determined by the difference in weight of the plates before and after particle deposition. The particle size associated with each plate is determined from sampling parameters. An Anderson Mark V impactor was used for this analysis.

3.3 Boiler Efficiency Calculations

Overall boiler efficiences were determined by the stack loss method. This method includes the determination of combustion efficiency and heat transfer efficiency. Combustion efficiency is calculated as the percentage represented by the actual heat produced in the firebox relative to the total heat production of the fuel consumed. Heat transfer efficiency is calculated as the percentage represented by the useful heat released to the boiler water relative to the actual heat produced in the firebox. Overall efficiency is calculated as the product of combustion efficiency and heat transfer efficiency.

4.0 RESULTS

Particulate emission results have been calculated in terms of mg/m^3, mg/m^3 @ 12% CO_2, kg/h, and kg/GJ of useful heat output. The total emission concentration ranged from 59.7 to 280 mg/m^3 for the eight tests conducted (Table 1). The total mass emission rate however showed a broader range, from 0.062 to 33.8 kg/GJ of useful heat output.

The gravimetric results (Table 2) indicate that, during the slow burn cycles, between 55 and 75 percent of the collected total emission was contributed by the back-half or condensable component of the sampling train. During the hot burn cycles only 14 to 25 percent of the material collected was condensable matter.

Nitrogen oxides were generally 2 mg/m^3 or less during the slow burn cycles and between 10 and 15 mg/m^3 during the hot burn cycles.

Table 4 and Figure 3 present particle size data for one hot and one slow burn, indicating that the Dp 50 (diameter with 50% by weight less than the stated size) for the hot burn was 2.6 microns (u) compared to 1.4 u for the slow burn.

Boiler efficiencies are presented in Table 3. The results show that overall efficiencies were in the 80-90 percent range for hot burns but ranged from 6 to 78 percent for slow burns depending on the fuel type.

Appendix I shows that all samples were collected isokinetically indicating that no bias due to particle size was introduced.

A list of the most commonly occuring hydrocarbons and their concentrations for each test is presented in Table 5. Phenolic compounds were determined to be the most abundant non-POM species. Very little POM material was detected.

TABLE 1 EMISSION RESULTS

Test No.	Condition	Stack Temp.	Flow Rate	Velocity	O_2	Flue Gas Composition CO_2	CO	H_2O	NO_x	Total Emissions			
		(°C)	(m^3/s)	(m/s)	(% dry)	(%)	(%)	(%)	(mg/m^3*)	(mg/m^3*)	(mg/m^3* @ 12% CO_2)	(kg/h) (kg/hr)	(kg/GJ)
1	Dry/Slow	65.8	0.060	1.47	20.0	0.6	0.1	3.2	1.9	68.4	1370	0.015	0.866
2	Dry/Hot	111	0.25	7.00	14.8	5.7	0.05	5.3	10.7	84.0	177	0.074	0.093
3	Dry/Slow	61.1	0.060	1.44	19.1	1.1	0.16	2.5	-	135	1472	0.029	0.635
4	Cord/Hot	104	0.25	7.06	14.0	6.6	0.025	6.1	14.0	67.7	123	0.060	0.067
5	Cord/Slow	57.2	0.058	1.41	18.6	1.8	0.2	2.3	0.3	60.2	402	0.013	0.192
6	Dry/Hot	105	0.23	6.83	14.9	5.5	0.05	6.7	-	59.7	130	0.050	0.062
7	Green/Hot	96.1	0.26	7.21	16.3	4.4	0.1	5.7	12.1	61.1	167	0.056	0.118
8	Green/Slow	51.7	0.054	1.29	19.9	1.0	0.2	2.4	2.0	280	3362	0.054	33.8

* mg/m^3 @ standard conditions of 20°C and 101.3 kPa (dry).

TABLE 2 GRAVIMETRIC RESULTS

Test	Condition	Front Half		Back Half				
		Front Filter	Probe Wash	Impingers	Back Filter	Front Half	Back Half	Volatiles
No.		(mg)	(mg)	(mg)	(mg)	(%)	(%)	(%)
1	Dry/Slow	1.8	4.8	11.2	7.0	26.6	73.4	91.1
2	Dry/Hot	30.0	11.4	7.1	2.2	81.7	18.3	39.0
3	Dry/Slow	2.7	12.3	15.0	19.7	30.2	69.8	92.6
4	Cord/Hot	28.2	3.3	8.3	0.8	77.6	22.4	46.3
5	Cord/Slow	3.1	5.5	8.8	2.9	42.4	57.6	86.7
6	Dry/Hot	17.0	4.2	6.5	0.4	75.4	24.6	48.8
7	Green/Hot	33.2	14.4	7.6	0.4	85.6	14.4	39.6
8	Green/Slow	17.1	7.6	18.7	47.5	27.2	72.8	96.9

TABLE 3 BOILER EFFICIENCIES, EMISSIONS AND USEFUL HEAT

Test No.	Condition	Fuel Heat Value (kJ/ODkg)	Combustion Eff. (%)	Heat Trans Eff. (%)	Overall Eff. (%)	Useful Heat (kW)	Total Emissions (Kg/GJ)
1	Dry/Slow	4212	82.4	57.0	46.9	4.7	0.866
2	Dry/Hot	4212	98.6	88.4	87.2	222	0.093
3	Dry/Slow	4212	83.3	80.0	66.6	13	0.635
4	Cord/Hot	4212	98.9	89.1	88.1	225	0.067
5	Cord/Slow	4212	90.1	86.4	77.8	18	0.192
6	Dry/Hot	4212	98.7	89.4	88.2	225	0.062
7	Green/Hot	4208	97.1	83.6	81.2	132	0.118
8	Green/Slow	4208	34.6	16.4	5.7	0.44	33.8

Fuel Moisture Content

Dry chips & cordwood =	10.7%
Green chips =	29.5%

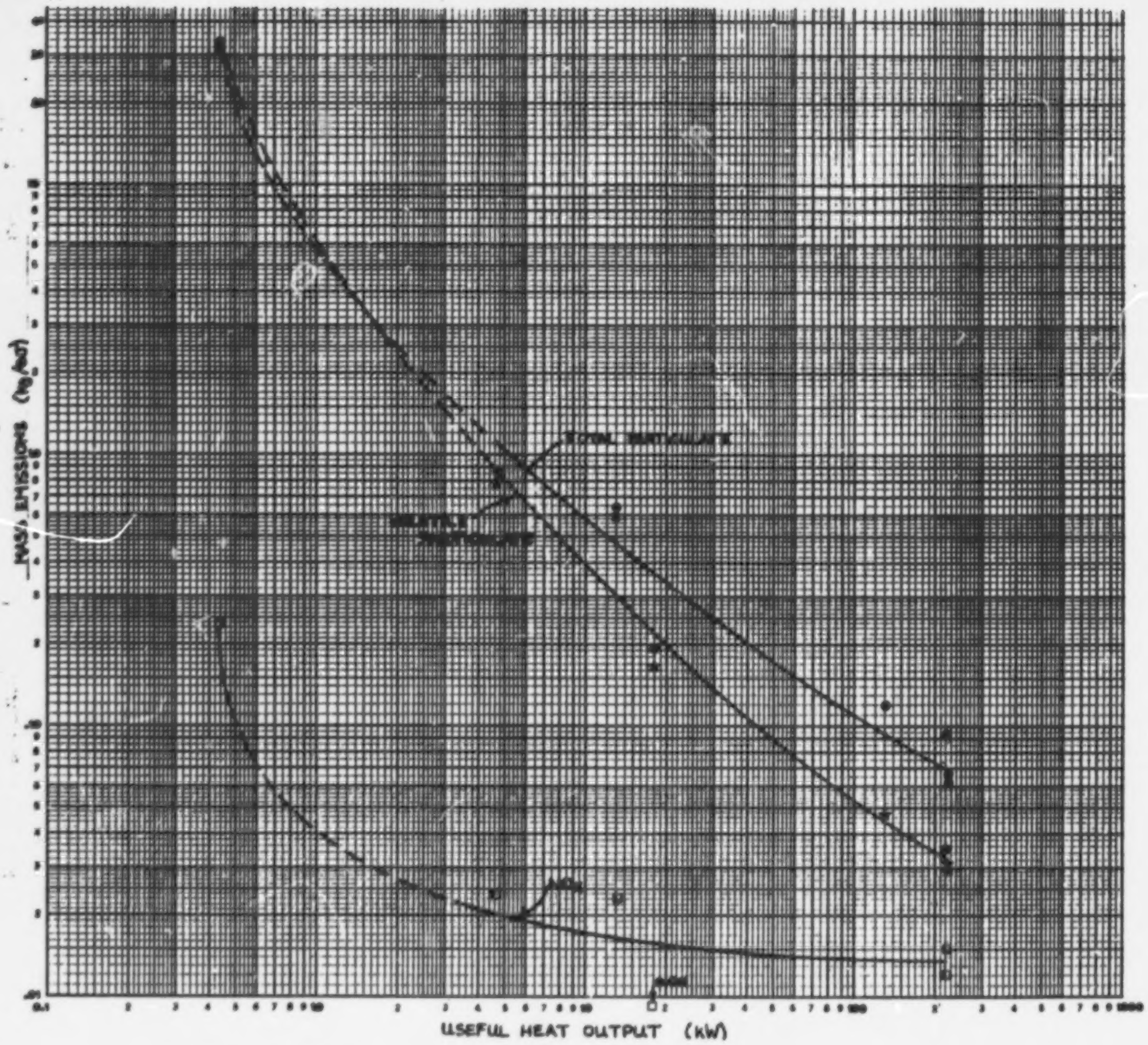


FIG 2 EMISSION RATE vs HEAT OUTPUT

TABLE 4 PARTICLE SIZING DATA

	Plate	Weight (mg)	% of Total Weight	Cumulative %	Dp (u)
HOT	1	1.1	7.2	100	14.8
FIRE	2	1.1	7.2	92.8	9.3
	3	2.4	15.7	85.6	6.1
	4	2.4	15.7	69.9	4.3
	5	2.4	15.7	54.2	3.2
	6	2.7	17.6	38.5	1.4
	7	1.2	7.8	20.9	0.85
	Filter	2.0	13.1	13.1	0.58
	Total	15.3	100	-	-

	Plate	Weight (mg)	% of Total Weight	Cumulative %	Dp (u)
SLOW	1	0.1	0		
FIRE	2	0.1	0		
	3	0.1	0		
	4	0.05	0.7	100	6.2
	5	1.7	22.5	99.3	4.0
	6	3.3	43.7	76.8	2.0
	7	0.9	11.9	33.1	1.25
	Filter	1.6	21.2	21.2	0.9
	Total	7.55	100	-	-

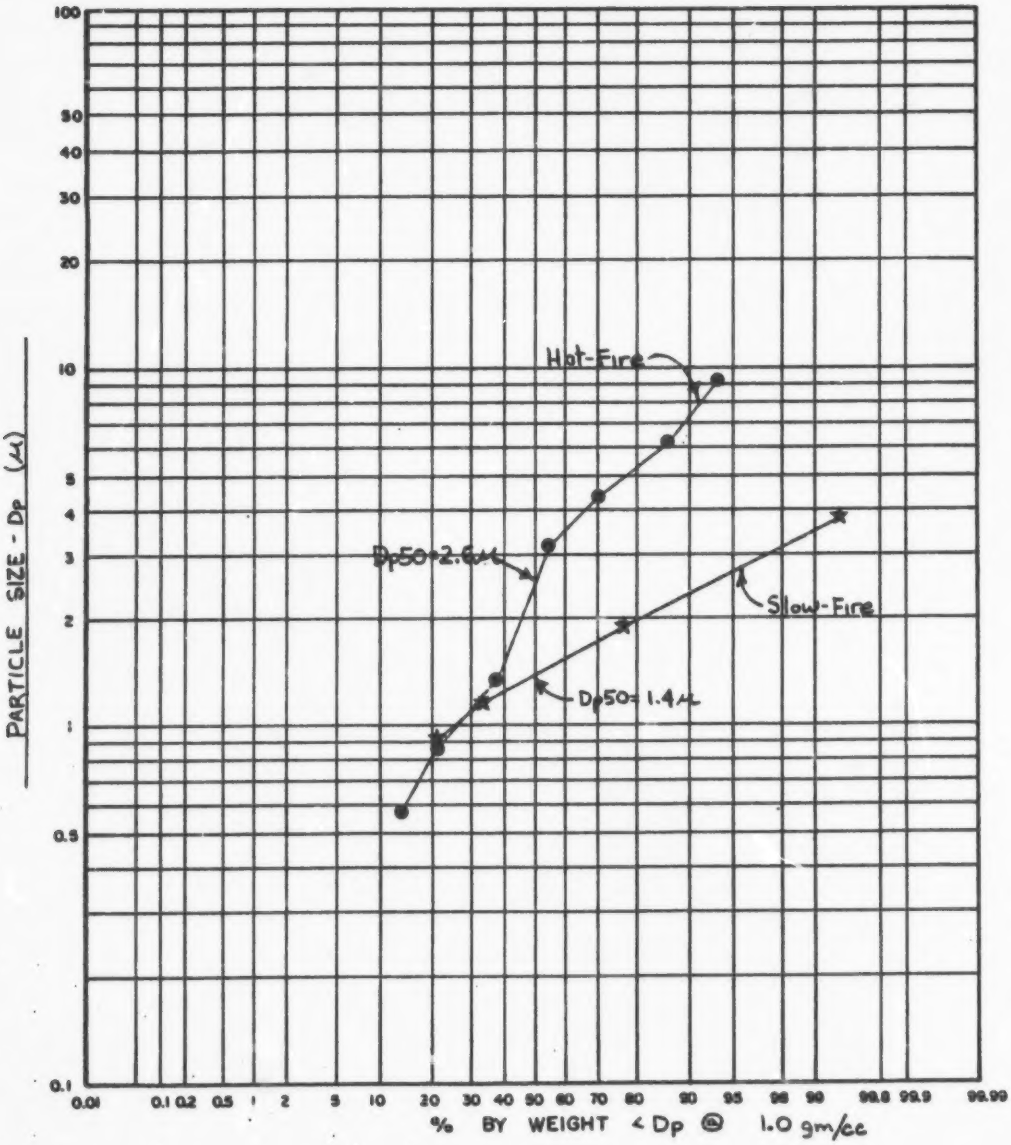


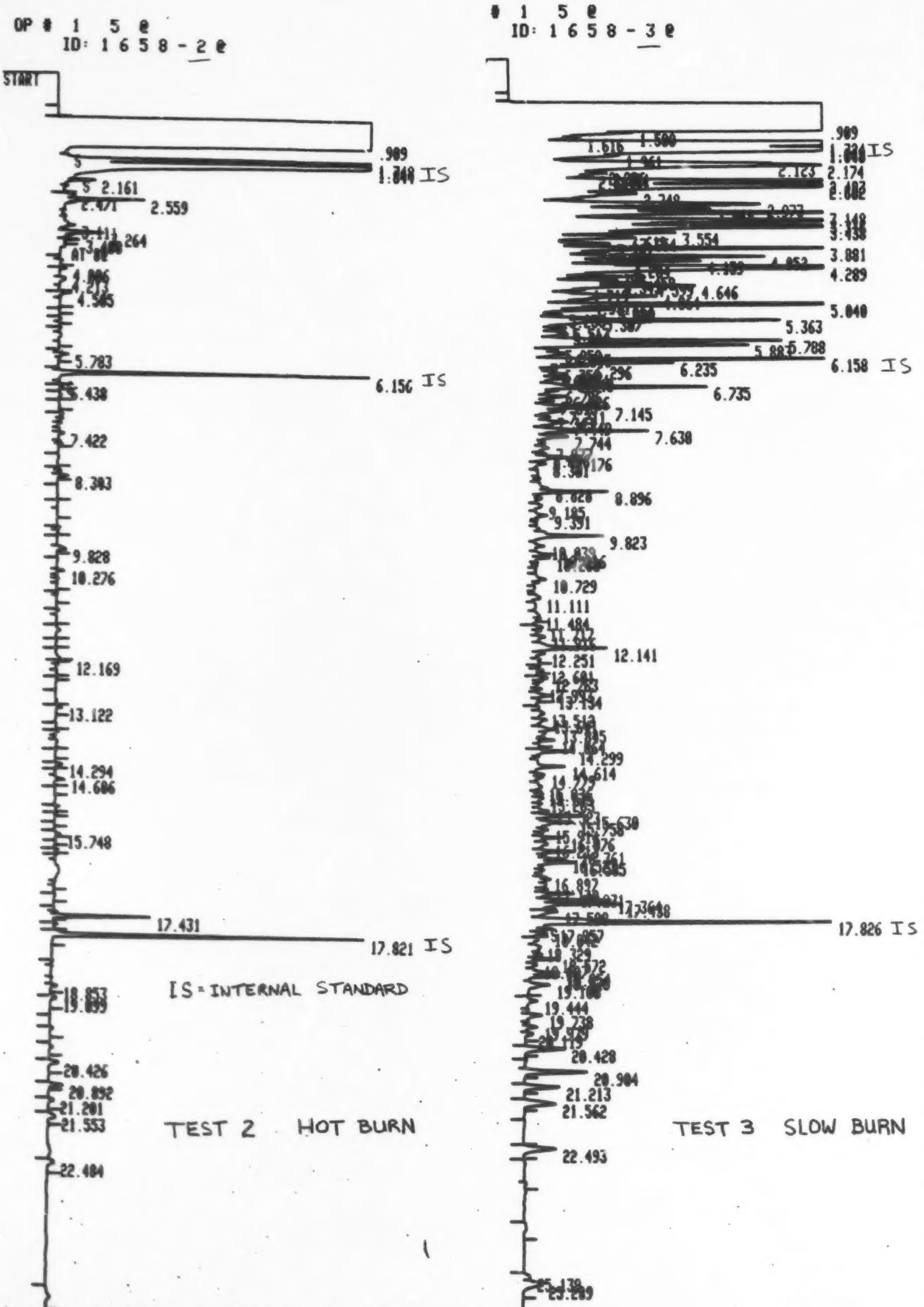
FIG. 3 PARTICLE SIZE vs % LESS THAN Dp

TABLE 5
HYDROCARBON EMISSIONS

Compound	Test No. 1	2	3	6	7	8
			(mg/m^3)			
POMs						
Phenantharene/ Anthracene	0.08	-	-	-	-	-
Naphthalene	-	-	-	-	-	0.16
non-POMs						
Phenol	16	0.4	27	0.3	1.5	20
Methyl Phenol* (isomer)	1.3	-	2.6	-	-	-
Methyl Phenol* (isomer)	3.4	0.07	6.0	0.08	-	-
Methoxy Phenol	6.6	-	12	-	-	16
Dimethyl Phenol (isomer)	3.2	-	6.0	-	-	2.1
Dimethoxy Phenol (isomer)	10.4	-	18	-	-	18
1- (2,4 Dihydroxyphenol) Ethanone	4.6	-	6.0	-	-	6.0
2- Methoxy-4-(2-Propenyl) Phenol	2.2	-	6.3	-	0.2	3.0
2- Methoxy-4-Propyl Phenol	0.4	-	2.3	-	-	1.3
Hydroxymethoxy Benzaldehyde	0.2	-	0.4	-	-	0.03
2- Methoxy-4-(1-Propenyl) Phenol	0.2	-	1.0	-	-	1.3
Bis (2-Ethyl Hexyl) Phthalate	0.7	0.3	0.4	-	-	-

- not detectable

* cresols



TEST 2 HOT BURN

TEST 3 SLOW BURN

FIG. 4 CHROMATOGRAMS

5.0 DISCUSSION

Total emissions from the wood fired boiler at the Pelly Crossing school are defined as the front half plus the back half (condensable) catch as determined using a modified EPA Method 5 procedure.

During the survey it was observed that visible emissions were continuous for the slow fire mode and intermittent for the hot fire mode. The continuous emissions of the slow fire cycles resulted from the smoldering of the fuel remaining on the combustion chamber following a hot fire cycle. The intermittent visible emissions during the hot fire cycles were caused by the physical disturbance of the fuel bed by the continuous auger feed of raw fuel from beneath the burning layer of fuel.

Slow fire cycles were sampled approximately fifteen minutes following aquastat shut-off, except for Test 1 where sampling commenced immediately following aquastat shut-off. Tests 1 and 3 were therefore duplicate fuel tests but were started at different times in the slow fire cycle.

The overall results of the survey are consistent with those expected from this type of wood fired appliance. Total emissions were generally in the same order of magnitude for all tests on a concentration basis but covered a large range as a function of useful heat output. Nitrogen oxide concentrations were at a maximum during hot fire cycles and hydrocarbons and carbon monoxide were at a maximum during slow fire cycles.

Particle size analysis revealed that emissions were more coarse during hot fire cycles than slow fire cycles. This was primarily due to the effect of the fan on for hot firing. With the fan off during slow firing many large particles would remain in the combustion zone due to gravitational forces. With the fan on, particles similar in size to those of the slow fire cycle would be entrained in the exhaust gases, some of which would be removed by the cyclone prior to discharge.

As expected, the hydrocarbon component of the total emissions increased significantly from hot to slow firing. Most of the components indicated by GC analysis as part of the hot fire cycle particulate were identified in the slow fire particulate for the same fuel. A great many more components were indicated (Figure 4) for slow fire samples however.

Phenols and cresols were found to be the most abundant non-POM hydrocarbons in all analyzed samples. These compounds accounted for 71% of Test 1 volatiles, 61% of Test 3 volatiles and 25% of Test 8 volatiles. They accounted for from 0.5 to 3% of hot fire test volatiles.

The chromatograms shown in Figure 4 represent one hot burn (Test 2) and one slow burn (Test 3). The peaks in each chromatogram are marked by numbers which increase in magnitude from left to right. These numbers represent the time at which the instrument detector sees a particular compound. Ignoring the initial solvent peak at .909 and the internal standars, the instrument detected about 30 compounds in Test 2 and over 100 in Test 3. The compounds detected early in the chromotographic run generally are lower molecular weight hydrocarbons than those detected later in the run.

The phenol and cresol compounds are the major peaks detected before the 8 minute mark and the phthalate was detected at the 17.4 minute mark in both samples. Good examples of compounds identified in both runs are the compounds detected at 9.828 in Test 2 and 9.823 in Test 3, at 12.169 in Test 2 and 12.141 in Test 3, and at 22.484 in Test 2 and 22.493 in Test 3. More significant compound matches occurred in the early part of the chromatograms.

Bis (2-Ethyl Hexyl) Phthalate is not a normal constituent of wood smoke. The presence in Test 1, 2 and 3 of this material, a plasticizer, suggests the combustion of plastic material in the boiler prior to the test program.

POM hydrocarbons were identified in only two of six analyzed samples (Test 1 and Test 8), both slow burns. The results of this portion of the survey are somewhat inconclusive due to the relatively small amounts of sample (12 to 50 mg). A larger sample size may have enabled identification of other POMs. In any event, the cencentrations of any POMs not determined in this study would not exceed those values for naphthalene and phenantharene/anthracene reported in Table 5.

Overall efficiency was very similar for the hot fire modes using dry chips and cordwood. The efficiency for hot fire using green chips was slightly less than those for dry chips/cordwood, indicating the effect of wood moisture on available heat output. The overall boiler efficiencies for slow fire modes were not consistent, indicating the range of available heat output for different fuels in this operating mode.

The Government of Yukon has not established emission guidelines. In the province of British Columbia discharges from this process would fall under the jurisdiction of the Waste Management Branch which has published guidelines for the forest products industry. The "Level A" or most stringent guideline, for wood-fired boilers is 230 mg/m^3 @ 12% CO_2 not including the condensable component. The results of this survey for hot fire cycles would therefore be well within the guidelines for British Columbia. Slow fire cycles would most likely be considered as "unit going down" or non-combustion source, and therefore would not fall under the same criteria.

The results published in this report represent emission characteristics for the fuels and operating conditions encountered on the test dates.

6.0 REFERENCES CONSULTED

1. B.C. Ministry of Environment "Source Testing Code for the Determination of Emissions of Particulates from Stationary Sources" 1983.

2. Oregon DEQ, "Standard Method for Measuring the Emission and Efficiencies of Residential Woodstoves" June 1984.

3. Oregon DEQ, "Source Sampling Methods 5 and 7"

4. B.C. Ministry of Environment, "A Laboratory Manual for the Chemical Analysis of Ambient Air, Emissions, Precipitation, Soil and Vegetation "April 1983.

5. Merlyn Hough and Barbara Tombleson, "Comparison of Woodstove Emission Test Results Using a Modified EPA Method 5 and a Simplified Method "PNWIS-APCA Paper, November 1983.

6. Anderson Mark V Operating Manual.

7. US EPA, "Supplement No. 14 for Compilation of Air Pollutant Emission Factors, Third Edition" May 1983.

8. Pers. Comm. Merlyn Hough, Oregon DEQ February, 1985.

9. Pers. Comm. Robert Lebens, Oregon DEQ March, 1985.

APPENDIX 1

Computer Outputs

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                    CONSULTANTS EMISSION SURVEY

                          GOVT OF YUKON

PELLY BOILER-SLOW DRY                      11:22-12:30  MARCH 5 , 1985.

-------------------------------------------------------------------------

LOCATION : STACK EXHAUST                TEST RESULTS      RUN NO - 1
-------------------------------------------------------------------------

         ROOT DELTA P AVG...........        0.078  INCHES H20

         AVG STACK TEMP..........           610.4  DEGREES R

         BAR PRESS      ..........          28.75  INCHES HG

         ABS STACK PRESS..........          28.75  INCHES HG

         FLUE GAS MW..........              28.54  LB/LB MOLE

         MOISTURE CONTENT..........         0.032  FRACTION

         OXYGEN..........                  20.000  PERCENT

         CARBON DIOXIDE..........           0.600  PERCENT

         AVG VELOCITY..........             4.813  FT/SEC

         ISOKINETIC VARIATION..........    101.89  PERCENT

         DISCHARGE STANDARD..........       126.8  SCFM

         DISCHARGE ACTUAL..........         157.7  ACFM

         PARTICULATE LOADING..........     0.0299  GR/SCF

         PARTICULATE LOADING..........     1.6455  MG/MOL

         PARTICULATE LOADING..........     0.5984  GR/@12%CO2

         PARTICULATE LOADING..........       0.03  LBS/HR
```

CONSULTANTS EMISSION SURVEY

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                        GOVT OF YUKON

PELLY BOILER-HOT DRY                      15:00-15:51  MARCH 5 , 1985.

-------------------------------------------------------------------------

LOCATION : STACK EXHAUST                  TEST RESULTS      RUN NO - 2
-------------------------------------------------------------------------

          ROOT DELTA P AVG...........       0.347  INCHES H2O

          AVG STACK TEMP..........          691.0  DEGREES R

          BAR PRESS      ..........         28.72  INCHES HG

          ABS STACK PRESS..........         28.72  INCHES HG

          FLUE GAS MW..........             28.90  LB/LB MOLE

          MOISTURE CONTENT..........        0.053  FRACTION

          OXYGEN..........                 14.800  PERCENT

          CARBON DIOXIDE..........          5.700  PERCENT

          AVG VELOCITY..........           22.952  FT/SEC

          ISOKINETIC VARIATION..........    99.58  PERCENT

          DISCHARGE STANDARD..........      522.4  SCFM

          DISCHARGE ACTUAL..........        751.9  ACFM

          PARTICULATE LOADING..........    0.0367  GR/SCF

          PARTICULATE LOADING..........    2.0208  MG/MOL

          PARTICULATE LOADING..........    0.0774  GR/@12%CO2

          PARTICULATE LOADING..........      0.16  LBS/HR
```

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                         CONSULTANTS EMISSION SURVEY

                               GOVT OF YUKON

PELLY BOILER-SLOW DRY                          16:46-17:50  MARCH 5 , 1985.

-----------------------------------------------------------------------------

LOCATION : STACK EXHAUST                     TEST RESULTS      RUN NO - 3
-----------------------------------------------------------------------------

          ROOT DELTA P AVG...........         0.077  INCHES H2O

          AVG STACK TEMP..........            602.0  DEGREES R

          BAR PRESS      ..........           28.71  INCHES HG

          ABS STACK PRESS..........           28.71  INCHES HG

          FLUE GAS MW..........               28.66  LB/LB MOLE

          MOISTURE CONTENT..........          0.025  FRACTION

          OXYGEN..........                   19.100  PERCENT

          CARBON DIOXIDE..........            1.100  PERCENT

          AVG VELOCITY..........              4.713  FT/SEC

          ISOKINETIC VARIATION..........     103.70  PERCENT

          DISCHARGE STANDARD..........        126.7  SCFM

          DISCHARGE ACTUAL..........          154.4  ACFM

          PARTICULATE LOADING..........      0.0590  GR/SCF

          PARTICULATE LOADING..........      3.2435  MG/MOL

          PARTICULATE LOADING..........      0.6433  GR/@12%CO2

          PARTICULATE LOADING..........        0.06  LBS/HR
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                    CONSULTANTS EMISSION SURVEY

                           GOVT OF YUKON

PELLY BOILER-CORD DRY                      10:20-11:06  MARCH 6 , 1985.

------------------------------------------------------------------------
LOCATION : STACK EXHAUST                   TEST RESULTS      RUN NO - 4
------------------------------------------------------------------------

          ROOT DELTA P AVG...........      0.349  INCHES H2O

          AVG STACK TEMP..........         679.0  DEGREES R

          BAR PRESS      ..........        28.02  INCHES HG

          ABS STACK PRESS..........        28.02  INCHES HG

          FLUE GAS MW..........            28.91  LB/LB MOLE

          MOISTURE CONTENT..........       0.061  FRACTION

          OXYGEN..........                14.000  PERCENT

          CARBON DIOXIDE..........         6.600  PERCENT

          AVG VELOCITY..........          23.159  FT/SEC

          ISOKINETIC VARIATION..........   99.78  PERCENT

          DISCHARGE STANDARD..........     518.8  SCFM

          DISCHARGE ACTUAL..........       758.7  ACFM

          PARTICULATE LOADING..........   0.0296  GR/SCF

          PARTICULATE LOADING..........   1.6262  MG/MOL

          PARTICULATE LOADING..........   0.0538  GR/@12%CO2

          PARTICULATE LOADING..........     0.13  LBS/HR
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                   CONSULTANTS EMISSION SURVEY


                         GOVT OF YUKON

ELLY BOILER-SLOW CORD                    12:12-13:15  MARCH 6 , 1985.

-----------------------------------------------------------------------
OCATION : STACK EXHAUST                  TEST RESULTS      RUN NO - 5
-----------------------------------------------------------------------
        ROOT DELTA P AVG...........        0.075  INCHES H2O

        AVG STACK TEMP..........           595.0  DEGREES R

        BAR PRESS      ..........          28.03  INCHES HG

        ABS STACK PRESS..........          28.03  INCHES HG

        FLUE GAS MW..........              28.77  LB/LB MOLE

        MOISTURE CONTENT..........         0.023  FRACTION

        OXYGEN..........                  18.600  PERCENT

        CARBON DIOXIDE..........           1.800  PERCENT

        AVG VELOCITY..........             4.609  FT/SEC

        ISOKINETIC VARIATION..........     98.05  PERCENT

        DISCHARGE STANDARD..........       122.6  SCFM

        DISCHARGE ACTUAL..........         151.0  ACFM

        PARTICULATE LOADING..........     0.0263  GR/SCF

        PARTICULATE LOADING..........     1.4481  MG/MOL

        PARTICULATE LOADING..........     0.1755  GR/@12%CO2

        PARTICULATE LOADING..........       0.03  LBS/HR
```

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                 CONSULTANTS EMISSION SURVEY


                        GOVVT OF YUKON

PELLY BOILER-HOT DRY                    15:05-15:51  MARCH 6 , 1985.

----------------------------------------------------------------------
LOCATION : STACK EXHAUST                  TEST RESULTS      RUN NO - 6
----------------------------------------------------------------------

          ROOT DELTA P AVG...........       0.335   INCHES H20

          AVG STACK TEMP..........          681.0   DEGREES R

          BAR PRESS      ..........         27.90   INCHES HG

          ABS STACK PRESS..........         27.90   INCHES HG

          FLUE GAS MW..........             28.71   LB/LB MOLE

          MOISTURE CONTENT..........        0.067   FRACTION

          OXYGEN..........                 14.900   PERCENT

          CARBON DIOXIDE..........          5.500   PERCENT

          AVG VELOCITY..........           22.390   FT/SEC

          ISOKINETIC VARIATION..........    98.29   PERCENT

          DISCHARGE STANDARD..........      494.9   SCFM

          DISCHARGE ACTUAL..........        733.5   ACFM

          PARTICULATE LOADING..........    0.0261   GR/SCF

          PARTICULATE LOADING..........    1.4371   MG/MOL

          PARTICULATE LOADING..........    0.0570   GR/@12%CO2

          PARTICULATE LOADING..........      0.11   LBS/HR
```

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                    CONSULTANTS EMISSION SURVEY

                         GOVT OF YUKON

PELLY BOILER-HOT GREEN                   09:15-10:01  MARCH 7 , 1985.

------------------------------------------------------------------------
LOCATION : STACK EXHAUST                 TEST RESULTS      RUN NO - 7
------------------------------------------------------------------------

         ROOT DELTA P AVG...........        0.358  INCHES H20
         AVG STACK TEMP..........           665.0  DEGREES R
         BAR PRESS       ..........         27.91  INCHES HG
         ABS STACK PRESS..........          27.91  INCHES HG
         FLUE GAS MW..........              28.71  LB/LB MOLE
         MOISTURE CONTENT..........         0.057  FRACTION
         OXYGEN..........                  16.300  PERCENT
         CARBON DIOXIDE..........           4.400  PERCENT
         AVG VELOCITY..........            23.641  FT/SEC
         ISOKINETIC VARIATION..........    100.05  PERCENT
         DISCHARGE STANDARD..........       540.9  SCFM
         DISCHARGE ACTUAL..........         774.5  ACFM
         PARTICULATE LOADING..........     0.0267  GR/SCF
         PARTICULATE LOADING..........     1.4671  MG/MOL
         PARTICULATE LOADING..........     0.0728  GR/@12%CO2
         PARTICULATE LOADING..........       0.12  LBS/HR
```

CONSULTANTS EMISSION SURVEY

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                              GOVT OF YUKON

PELLY BOILER-SLOW GREEN                       10:56-12:00  MARCH 7 , 1985.

------------------------------------------------------------------------------
LOCATION : STACK EXHAUST                   TEST RESULTS      RUN NO - 8
------------------------------------------------------------------------------

          ROOT DELTA P AVG...........      0.069  INCHES H2O

          AVG STACK TEMP..........         585.0  DEGREES R

          BAR PRESS      ..........        27.92  INCHES HG

          ABS STACK PRESS..........        27.92  INCHES HG

          FLUE GAS MW..........            28.69  LB/LB MOLE

          MOISTURE CONTENT..........       0.024  FRACTION

          OXYGEN..........                19.900  PERCENT

          CARBON DIOXIDE..........         1.000  PERCENT

          AVG VELOCITY..........           4.219  FT/SEC

          ISOKINETIC VARIATION..........  101.90  PERCENT

          DISCHARGE STANDARD..........     113.6  SCFM

          DISCHARGE ACTUAL..........       138.2  ACFM

          PARTICULATE LOADING..........   0.1224  GR/SCF

          PARTICULATE LOADING..........   6.7340  MG/MOL

          PARTICULATE LOADING..........   1.4692  GR/@12%CO2

          PARTICULATE LOADING..........     0.12  LBS/HR
```

APPENDIX 2

Formulae and Nomenclature for Emission Calculations

FORMULAE

1. $Wp = Wf + Ww$

2. $Pm = Pb + \frac{\Delta H}{13.6}$

3. $Ps = Pb + \frac{\Delta Ps}{13.6}$

4. $Vm_{STD} = \frac{VmPm}{Tm} \times \frac{T_{STD}}{P_{STD}}$

5. $gr/SCF = \frac{Wp \times 15.43}{Vm_{STD}}$

6. $Vs = 85.48\ Cp\sqrt{\Delta p}\ \text{avg.} \sqrt{\frac{Ts}{Ms \times Ps}}$

7. $Md = .44(\%CO_2) + .32(\%O_2) + .28\ (\%CO + \%N_2)$

8. $Ms = Md\ (\frac{100 - \%H_2O}{100}) + .18(\%H_2O)$

9. $V_{TOT} = Vm_{STD} + Vc_{STD}$

10. $\%H_2O = \frac{Vc_{STD} \times 100\%}{V_{TOT}}$

11. $Vc_{STD} = Vc \times .0474$

12. $Q_A = Vs \times 60 \times As$

13. $Q_{STD} = Q_A \times \frac{T_{STD}}{Ts} \times \frac{Ps}{P_{STD}}\ (1 - \frac{\%H_2O}{100})$

14. $I = \frac{1.667\ Ts \left[.00267\ (Vc) + \frac{Vm}{Tm}\ (Pm) \right]}{\theta\ Vs\ Ps\ An}$

NOMENCLATURE

Wf = weight of particulate on filter (gm)
Ww = weight of particulate in washings (gm)
Wp = total weight of particulate (gm)
Vm = gas meter sample volume (ft^3)
Vm_{STD} = gas meter sample volume @ standard conditions (ft^3)
Pb = barometric pressure (mmHg or "Hg)
ΔPs = stack static pressure ("H_2O)
Pm = meter pressure (mmHg or "Hg)
Ps = stack pressure (mmHg or "Hg)
ΔH = orifice differential pressure ("H_2O)
Θ = sample time total (min)
Tm = meter temperature (°R)
T_{STD} = 528°R
P_{STD} = 760 mm Hg or 29.92 "Hg
Vs = average stack gas velocity (ft/sec)
Cp = pitot correction factor (dimensionless)
$\sqrt{\Delta p}$ avg. = average velocity pressure "$H_2O^{1/2}$
Md = molecular weight dry (lb/lb mole)
Ms = molecular weight wet (lb/lb mole)
$\%H_2O$ = percent water vapour
Vc = volume of condensate collected (mL)
Vc_{STD} = standard volume of moisture (ft^3)
I = overall isokinetic variation (%)
Q_A = volumetric flowrate at stack conditions (ft^3/min)
An = sample nozzle area (ft^2)
Q_{STD} = volumetric flowrate at standard conditions (STD ft^3/min)
As = area of stack (ft^2)

APPENDIX 3

Field Data Sheets

B-1

STACK SURVEY DATA

PLANT [illegible]
RUN NO. [illegible]
LOCATION [illegible]
DATE [illegible]
OPERATOR
SAMPLE UNIT S/N
CONTROL UNIT S/N
AMBIENT TEMPERATURE, °F
BAROMETRIC PRESSURE, IN. Hg 28.75
ASSUMED MOISTURE, Bw

PROBE TIP DIAMETER, IN. .451
PROBE LENGTH, FT.
PROBE HEATER SETTING

INITIAL LEAK TEST [illegible]
FINAL LEAK TEST .02
METER TEMP. COMP. ☐

.5464 ft²
Cp .837

HEATER BOX SETTING, °F
ASSUMED MOL. WT. (DRY)
ASSUMED MOL. WT. (WET)
STATIC PRESSURE, IN., H_2O .05
FILTER NUMBER
CONDENSATE COLLECTED, ml [illegible]
VELOCITY, FT./SEC.
FLOW, SCFS
STACK DIAMETER
STACK HEIGHT

POINT	CLOCK TIME	DRY GAS METER, FT³	VOL./PT.	PITOT, IN. H_2O ΔP	ORIFICE ΔH, IN. H_2O	DRY GAS TEMP. °F		PUMP VACUUM, IN. Hg GAUGE	BOX TEMP, °F	IMPINGER TEMP., °F	STACK TEMP., °F	ISOKINETIC %	
						INLET	OUTLET					MID	FINAL
	[illegible]	715.575											
1		[illegible]	1.015	[illegible]	[illegible]						[illegible]	.077	
2		[illegible]	1.09								[illegible]	.034	
3		[illegible]	1.00	[illegible]		–					[illegible]	.034	
4		[illegible]	.82	[illegible]							[illegible]	.065	
5		[illegible]	1.03	[illegible]							[illegible]	.051	
	1:52	[illegible]	1.52	[illegible]	[illegible]	70	[illegible]				[illegible]	.015	
	[illegible]	21											
[illegible]		[illegible]	.83	[illegible]	[illegible]						[illegible]	.063	
[illegible]		[illegible]	.87	[illegible]							[illegible]	.063	
[illegible]		[illegible]	.89	[illegible]	.11	[illegible]	[illegible]		300		[illegible]	.71	
[illegible]		[illegible]	.96	[illegible]		[illegible]	[illegible]				136	.71	
11		[illegible]	1.05	[illegible]	.13	[illegible]	74		[illegible]		135	.054	
12	12:30	727.16	1.01	.008	.15	[illegible]	74				134	.051	
Total	[illegible]	12.185			.13	33					150.4	Avg.	Avg.
Average		•F = 12.526										.078	

CO_2 1.0
O_2 19.9
CO 0.2

Plant ____________ Date ____________
Location ____________ Operators ____________
Test ____________ Analyst ____________

Moisture data

	Final weight (gm.)	Tare weight (gm.)	Weight of moisture (gm.)
Impinger #1	103	100	3
Impinger #2	101	100	1
Impinger #3	0	0	0
Impinger #4			0
	Total		
	Moisture volume		[illegible] ml.

Particulate data

	Final weight (gm.)	Tare weight (gm.)	Weight of particulate (gm.)
Filter			
Beaker with (probenozzle) washings			
Cyclone flask			
Beaker with (impinger filter—holder) contents and washings			
	Total (gm.)		
	Particulates in (mg.)		

1 49.50

P 2

STACK SURVEY DATA

PLANT Pelly
RUN NO. 2 Dry-hot Fuel
LOCATION [illegible]
DATE May 5/82
OPERATOR
SAMPLE UNIT S/N
CONTROL UNIT S/N
AMBIENT TEMPERATURE, °F
BAROMETRIC PRESSURE, IN. Hg 25.72
ASSUMED MOISTURE, Bw

PROBE TIP DIAMETER, IN. .312
PROBE LENGTH, FT.
PROBE HEATER SETTING

INITIAL LEAK TEST ☑
FINAL LEAK TEST ☑
METER TEMP. COMP. ☐ Cp .848

HEATER BOX SETTING, °F
ASSUMED MOL. WT. (DRY)
ASSUMED MOL. WT. (WET)
STATIC PRESSURE, IN., H_2O 0
FILTER NUMBER 2
CONDENSATE COLLECTED, ml 23
VELOCITY, FT./SEC.
FLOW, SCFS
STACK DIAMETER
STACK HEIGHT

POINT	CLOCK TIME	DRY GAS METER, FT.³	VOL./PT.	PITOT, IN. H_2O ΔP	ORIFICE ΔH, IN. H_2O	DRY GAS TEMP. °F		PUMP VACUUM, IN. Hg GAUGE	BOX TEMP, °F	IMPINGER TEMP., °F	STACK TEMP., °F	ISOKINETIC %	
		7[illegible]				INLET	OUTLET					MID-	FINAL
1	15 00	2.01	1.71	.12	.75	45	46	3.5	300	ICED	211	.346	
2		3.72	1.71	.12	.76	54	45	3.5			215	.346	
3		5.42	1.70	.12	.76	56	44				217	.346	
4		7.43	2.01	.16	1.1	50	42		310		221	.40	
5		9.47	2.04	.16	1.1	50	41				224	.40	
6	15:21	61.60	2.13	.17	1.2	50	39				227	.402	
7	15 30	2.66	1.66	.04	.3	44	37				234	.260	
8		4.12	1.46	.09	.6	47	36				234	.300	
9		5.61	1.49	.10	.61	45	46	3	310		242	.316	
10		7.33	1.72	.12	[illegible]	[illegible]	[illegible]				[illegible]	.341	
11		69.12	1.79	[illegible]	.92	48	[illegible]				236	.374	
12	15:51	7[illegible]	1.73	.13	.81	48	37				2[illegible]	.341	
	35 pl												
Total	42.0	20.55 ft³			.81	45					231	Avg.	Avg.
Average		= 2[illegible]										.341	

177 [illegible]
244 [illegible]

Avg

CO_2	44
O_2	16.3
CO	0.1

Plant ______________ Date ______________

Location ______________ Operators ______________

Test ______________ Analyst ______________

Moisture data

	Final weight (g m.)	Tare weight (g m.)	Weight of moisture (g m.)
Impinger #1	111	100	11
Impinger #2	124	100	24
Impinger #3	4	0	4
Impinger #4			2
	Total		
	Moisture volume		41 ml.

Particulate data

	Final weight (g m.)	Tare weight (g m.)	Weight of particulate (g m.)
Filter			
Beaker with (probenozzle) washings			
Cyclone flask			
Beaker with (impinger filter—holder) contents and washings			
	Total (gm.)		
	Particulates in (mg.)		

2-73.30
.19

STACK SURVEY DATA

31 wet

PLANT [illegible]
RUN NO. 3 [illegible]
LOCATION Man 5
DATE
OPERATOR
SAMPLE UNIT S/N
CONTROL UNIT S/N
AMBIENT TEMPERATURE, °F
BAROMETRIC PRESSURE, IN. Hg [illegible]3.71
ASSUMED MOISTURE, Bw 2

PROBE TIP DIAMETER, IN. .40[illegible]
PROBE LENGTH, FT.
PROBE HEATER SETTING

INITIAL LEAK TEST .01
FINAL LEAK TEST .010
METER TEMP. COMP. 337

HEATER BOX SETTING, °F
ASSUMED MOL. WT. (DRY)
ASSUMED MOL. WT. (WET)
STATIC PRESSURE, IN., H_2O
FILTER NUMBER 3
CONDENSATE COLLECTED, ml 7
VELOCITY, FT./SEC.
FLOW, SCFS
STACK DIAMETER [illegible]
STACK HEIGHT

POINT	CLOCK TIME	DRY GAS METER, FT.³	VOL./PT.	PITOT, IN. H_2O ΔP	ORIFICE ΔH, IN. H_2O	DRY GAS TEMP. °F INLET	DRY GAS TEMP. °F OUTLET	PUMP VACUUM, IN. Hg GAUGE	BOX TEMP, °F	IMPINGER TEMP., °F	STACK TEMP., °F	ISOKINETIC % MID √ΔP	ISOKINETIC % FINAL
	4:46	[illegible]											
		71.721	.89	.004	.16	44	41	[illegible]	280	<60	160	.063	
2		2.82	.88	.004	.10	46					157	.063	
3		3.53	.91	.005	.12	36	35	<1	232		154	.071	
4		4.59	1.06	.006	.14	34	32				146	.077	
5		5.72	1.13	.007	.16	34	32				147	.084	
	:16	6.85	1.13	.007	.16	34	32	<1			143	.084	
7	5:20	[illegible]	1.24	.009	.16	34	32		310		133	.095	
8	fan wall	9.24	1.13	[illegible]	[illegible]	[illegible]	[illegible]					.084	
9		30.[illegible]	1.13	[illegible]	.16	34	32	<1			135	.084	
10		1.30	.93	.005	.11	33	31		310		136	.071	
11		2.23	.93	.005	.11	33	32				130	.071	
12	5:50 [illegible]	33.16	.93	.005	.11	30	34				129	.071	
	5/pt												
[illegible]	[illegible]	[illegible]		[illegible]			0						
	32 min												
	[illegible]	37.36		Bombed out on [illegible] (fan started)									
Total	60.0	12.31×F =			.14	34					142	Avg.	Avg.
Average		12.65										.077	

Avg	
CO_2	5.5
O_2	14.9
CO	0.05

Plant ____________________ Date ____________________

Location ____________________ Operators ____________________

Test ____________________ Analyst ____________________

Moisture data

	Final weight (gm.)	Tare weight (gm.)	Weight of moisture (gm.)
Impinger #1	111	100	11
Impinger #2	106	100	6
Impinger #3	1	0	1
Impinger #4			7
	Total		
	Moisture volume		25 ml.

Particulate data

	Final weight (gm.)	Tare weight (gm.)	Weight of particulate (gm.)
Filter			
Beaker with (probenozzle) washings			
Cyclone flask			
Beaker with (impinger filter—holder) contents and washings			
	Total (gm.)		
	Particulates in (mg.)		

PLANT Perry
RUN NO. 4 ... Dry
LOCATION Boiler Stk
DATE Mar 6
OPERATOR
SAMPLE UNIT S/N
CONTROL UNIT S/N
AMBIENT TEMPERATURE, °F
BAROMETRIC PRESSURE, IN. Hg 30.02
ASSUMED MOISTURE, Bw 5

PROBE TIP DIAMETER, IN. .312
PROBE LENGTH, FT.
PROBE HEATER SETTING

INITIAL LEAK TEST .02
FINAL LEAK TEST .03
METER TEMP. COMP. ✓

.348

HEATER BOX SETTING, °F
ASSUMED MOL. WT. (DRY)
ASSUMED MOL. WT. (WET)
STATIC PRESSURE, IN., H₂O 0
FILTER NUMBER 4
CONDENSATE COLLECTED, ml 27
VELOCITY, FT./SEC.
FLOW, SCFS
STACK DIAMETER
STACK HEIGHT

STACK SURVEY DATA

POINT	CLOCK TIME	DRY GAS METER, FT.³	VOL./PT.	PITOT, IN. H₂O ΔP	ORIFICE ΔH, IN. H₂O	DRY GAS TEMP. °F INLET	DRY GAS TEMP. °F OUTLET	PUMP VACUUM, IN. Hg GAUGE	BOX TEMP, °F	IMPINGER TEMP., °F	STACK TEMP., °F	ISOKINETIC % MID	ISOKINETIC % FINAL
		787.54											
	10:20												
1		88.77	1.23	.05	.36	44	51	2	300	197	21	.224	
2		90.30	1.53	.09	.68	47	41			205		.320	
3		91.89	1.59	[illegible]	[illegible]	45	43			[illegible]		.316	
4		93.67	1.78	.13	.83	44	45			215		.361	
5		5.59	1.92	.15	1.0	46	44			222		.357	
6	10:41	797.53	1.94	.15	1.0	45	43			215		.357	
7	10:45	9.48	1.95	16	1.05	42	38			215		.402	
8		801.44	1.96	16	1.05	40	35			215		.402	
9		3.24	1.80	.14	.88	40	30	3		224		.374	
10		4.96	1.72	.12	.75	40	30			223		.346	
11		6.64	1.68	.12	.75	40	29			227		.346	
12	11:06	808.34	1.70	.12	.78	40	28			228		.346	
Total	42.0	20.80 =			.82	41				219		Avg.	Avg.
Average		21.35										.349	

46.03

Avg

CO_2	1.8
O_2	18.6
CO	0.2

Plant ____________________ Date ____________________

Location ____________________ Operators ____________________

Test ____________________ Analyst ____________________

Moisture data

	Final weight (gm.)	Tare weight (gm.)	Weight of moisture (gm.)
Impinger #1	101	100	1
Impinger #2	101	100	1
Impinger #3	0		0
Impinger #4			4
	Total		
	Moisture volume		6 ml.

Particulate data

	Final weight (gm.)	Tare weight (gm.)	Weight of particulate (gm.)
Filter			
Beaker with (probenozzle) washings			
Cyclone flask			
Beaker with (impinger filter-holder) contents and washings			
	Total (gm.)		
	Particulates in (mg.)		

STACK SURVEY DATA

22

PLANT [illegible]
RUN NO. 5 [illegible]
LOCATION Stack
DATE Mar 6
OPERATOR
SAMPLE UNIT S/N
CONTROL UNIT S/N
AMBIENT TEMPERATURE, °F
BAROMETRIC PRESSURE, IN. Hg [illegible]
ASSUMED MOISTURE, Bw

PROBE TIP DIAMETER, IN. [illegible]
PROBE LENGTH, FT.
PROBE HEATER SETTING

INITIAL LEAK TEST ☐ .02
FINAL LEAK TEST ☐ .1
METER TEMP. COMP. ☐

837

HEATER BOX SETTING, °F
ASSUMED MOL. WT. (DRY)
ASSUMED MOL. WT. (WET)
STATIC PRESSURE, IN., H_2O
FILTER NUMBER 3
CONDENSATE COLLECTED, ml 6
VELOCITY, FT./SEC.
FLOW, SCFS
STACK DIAMETER [illegible]
STACK HEIGHT

POINT	CLOCK TIME	DRY GAS METER, FT.^{3}	VOL./PT.	PITOT, IN. $H_2O\Delta P$	ORIFICE ΔH, IN. H_2O	DRY GAS TEMP. °F		PUMP VACUUM, IN. Hg GAUGE	BOX TEMP, °F	IMPINGER TEMP., °F	STACK TEMP., °F	ISOKINETIC %	
						INLET	OUTLET					MID	FINAL
		321.69											
1	12:12	2.45	.79	.003	.09	[illegible]	25	-1	[illegible]	[illegible]	142	.055	
2		3.31	.83	.004	.10	29	27		300		141	.063	
3		4.21	.90	.005	.11	28	27				142	.071	
4		5.17	.96	.006	.12	29	26				140	.077	
5		6.13	.96	.006	.12	[illegible]	26				138	.077	
6	12:42	7.15	1.02	.007	.13	29	26				136	.084	
7	12:45	8.28	1.13	.008	.16	28	26				134	.089	
8		9.37	1.09	.007	.15	29	26				[illegible]	.084	
9		30.37	1.02	.006	.13	30	26				131	.077	
10		1.36	.99	.006	.13	30	26				129	.077	
11		2.23	.87	.005	.10	30	26				128	.071	
12	13:15	333.08	.85	.003	.10	30	26				130	.071	
Total	60.0	11.39×F =											
Average		11.71			.12	28					135	Avg. .075	Avg.

Avg

CO2 6.6
O2 14.0
CO .025

Plant ______________ Date ______________
Location ______________ Operators ______________
Test ______________ Analyst ______________

Moisture data

	Final weight (gm.)	Tare weight (gm.)	Weight of moisture (gm.)
Impinger #1	114	100	14
Impinger #2	111	100	11
Impinger #3	1	0	1
Impinger #4			3
	Total		
	Moisture volume		29 ml.

Particulate data

	Final weight (gm.)	Tare weight (gm.)	Weight of particulate (gm.)
Filter			
Beaker with (probenozzle) washings			
Cyclone flask			
Beaker with (impinger filter—holder) contents and washings			
	Total (gm.)		
	Particulates in (mg.)		

STACK SURVEY DATA

PLANT Pelly
RUN NO. 6 HOT-DRY
LOCATION Stack
DATE Nov. 4/75
OPERATOR
SAMPLE UNIT S/N
CONTROL UNIT S/N
AMBIENT TEMPERATURE, °F 20
BAROMETRIC PRESSURE, IN. Hg 27.90
ASSUMED MOISTURE, Bw 5

PROBE TIP DIAMETER, IN. .312
PROBE LENGTH, FT.
PROBE HEATER SETTING

INITIAL LEAK TEST .02
FINAL LEAK TEST .04
METER TEMP. COMP. lt
.848

HEATER BOX SETTING, °F
ASSUMED MOL. WT. (DRY)
ASSUMED MOL. WT. (WET)
STATIC PRESSURE, IN., H_2O 0
FILTER NUMBER 6
CONDENSATE COLLECTED, ml 25
VELOCITY, FT./SEC.
FLOW, SCFS
STACK DIAMETER
STACK HEIGHT

POINT	CLOCK TIME	DRY GAS METER, FT.³	VOL./PT.	PITOT, IN. H_2O ΔP	ORIFICE ΔH, IN. H_2O	DRY GAS TEMP. °F INLET	DRY GAS TEMP. °F OUTLET	PUMP VACUUM, IN. Hg GAUGE	BOX TEMP, °F	IMPINGER TEMP., °F	STACK TEMP., °F	ISOKINETIC % MID	ISOKINETIC % FINAL
		861.27											
1	15 05	2.53	1.26	.06	.4	31	28	3	[illegible]	60	203	.245	
2		4.04	1.51	.09	.6	43	32	3.5			206	.322	
3		5.54	1.50	.09	.6	44	33				210	.302	
4		7.19	1.65	.11	.71	44	33				215	.332	
5		9.04	1.85	.14	.5	44	33				[illegible]	314	
6	15 26	10.92	1.88	.14	.95	46	32	4.5			223	.314	
7	15 30	2.54	1.62	.10	.7	44	33				226	.316	
8		4.13	1.59	.10	.81	44	32				236	.316	
9		5.73	1.60	.10	.67	44	31				239	.316	
10		77.53	1.80	.14	.85	44	31				237	314	
11				.15								.387	
12	15 51			.15								.387	
	17:38												
	[illegible]	893.65		.14	.42	30	28				213		
	25"					38	28				227		
	17 58	904.30		14	.40	36	28				236		
		10.65					31						
18 30	[illegible] S/o	7.30	3.81	.027	.15	32	30				132		
:50	20 min	908.11											
Total	35.0	116.26 ft³			.72	35					221	Avg.	Avg.
Average		16.72										.325	

CO_2 1.1
O_2 19.1
CO .1 orsat .16 Drager

Plant ______________ Date ______________
Location ______________ Operators ______________
Test ______________ Analyst ______________

Moisture data

	Final weight (g m.)	Tare weight (g m.)	Weight of moisture (g m.)
Impinger #1	103		3
Impinger #2	101		1
Impinger #3	0		
Impinger #4			3
	Total		
	Moisture volume		7 ml.

Particulate data

	Final weight (g m.)	Tare weight (g m.)	Weight of particulate (g m.)
Filter			
Beaker with (probenozzle) washings			
Cyclone flask			
Beaker with (impinger filter—holder) contents and washings			
	Total (gm.)		
	Particulates in (mg.)		

STACK SURVEY DATA

PLANT Kelly
RUN NO. 7 [illegible] - [illegible]
LOCATION Boiler Stk
DATE [illegible] 7/85
OPERATOR
SAMPLE UNIT S/N
CONTROL UNIT S/N
AMBIENT TEMPERATURE, °F
BAROMETRIC PRESSURE, IN. Hg 27.91
ASSUMED MOISTURE, Bw 5

PROBE TIP DIAMETER, IN. ~~[illegible]~~ .376
PROBE LENGTH, FT.
PROBE HEATER SETTING

INITIAL LEAK TEST .01
FINAL LEAK TEST .01
METER TEMP. COMP. 1.0

HEATER BOX SETTING, °F
ASSUMED MOL. WT. (DRY)
ASSUMED MOL. WT. (WET)
STATIC PRESSURE, IN., H_2O .2
FILTER NUMBER 7
CONDENSATE COLLECTED, ml 41
VELOCITY, FT./SEC.
FLOW, SCFS
STACK DIAMETER 10
STACK HEIGHT

w.s
113 44
212 46

POINT	CLOCK TIME	DRY GAS METER, FT.³	VOL./PT.	PITOT, IN. H_2O ΔP	ORIFICE ΔH, IN. H_2O	DRY GAS TEMP. °F INLET	DRY GAS TEMP. °F OUTLET	PUMP VACUUM, IN. Hg GAUGE	BOX TEMP, °F	IMPINGER TEMP., °F	STACK TEMP, °F	ISOKINETIC % MID	ISOKINETIC % FINAL
	09:15	917.701											
1		19.95	2.25	.09	1.3	30	27	7	300	(60)	190	.300	
2		2.2[illegible]	2.31	10	1.4	41	25				194	.316	
3		4.70	2.44	.11	1.55	42	27				196	.332	
4		7.24	2.54	[illegible]	[illegible]	41	[illegible]					.361	
5		30.00	2.76	.15	2.1	41	27	10			[illegible]	.357	
6	9:36	2.80	2.80	15	2.1	41	27				202	.387	
											207	.387	
7	9:40	5.21	2.41	.11	1.55	31	26				209	.332	
8		7.73	2.52	.12	1.7	40	28				212	.346	
9		40.27	2.54	12	1.7	41	29	9			212	.346	
10		2.97	2.70	14	2.05	42	30				215	.374	
11		5.88	2.91	16	2.3	42	31				216	[illegible]	
12	[illegible]	48.87	2.99	17	2.4	42	30				219	.412	
Total	42.0	31.17+F=			1.83	34							
Average		32.64									205	Avg. .355	Avg.

	Avg
CO_2	5.7
O_2	14.8
CO	.1 Orsat .05 Draeger

Plant ______________ Date ______________

Location ______________ Operators ______________

Test ______________ Analyst ______________

Moisture data

	Final weight (gm.)	Tare weight (gm.)	Weight of moisture (gm.)
Impinger #1	116	100	16
Impinger #2	106	100	6
Impinger #3	1	0	1
Impinger #4	2	0	2
	Total		
	Moisture volume		25 ml.

Particulate data

	Final weight (gm.)	Tare weight (gm.)	Weight of particulate (gm.)
Filter			
Beaker with (probenozzle) washings			
Cyclone flask			
Beaker with (impinger filter—holder) contents and washings			
	Total (gm.)		
	Particulates in (mg.)		

STACK SURVEY DATA

PLANT Pelly
RUN NO. 8 [illegible]
LOCATION [illegible]
DATE [illegible]
OPERATOR [illegible]
SAMPLE UNIT S/N
CONTROL UNIT S/N
AMBIENT TEMPERATURE, °F [illegible]
BAROMETRIC PRESSURE, IN. Hg 27.92
ASSUMED MOISTURE, Bw

PROBE TIP DIAMETER, IN. [illegible]
PROBE LENGTH, FT.
PROBE HEATER SETTING

INITIAL LEAK TEST ☐
FINAL LEAK TEST ☐
METER TEMP. COMP. ☐

HEATER BOX SETTING, °F
ASSUMED MOL. WT. (DRY)
ASSUMED MOL. WT. (WET)
STATIC PRESSURE, IN., H_2O [illegible]
FILTER NUMBER
CONDENSATE COLLECTED, ml 6
VELOCITY, FT./SEC.
FLOW, SCFS
STACK DIAMETER
STACK HEIGHT

POINT	CLOCK TIME	DRY GAS METER, FT.^{3}	VOL./PT.	PITOT, IN. H_2O ΔP	ORIFICE ΔH, IN. H_2O	DRY GAS TEMP. °F		PUMP VACUUM, IN. Hg GAUGE	BOX TEMP, °F	IMPINGER TEMP., °F	STACK TEMP., °F	ISOKINETIC %	
						INLET	OUTLET					MID	FINAL
	11.52	47.35											
1		0.63	.93	[illegible]	[illegible]			[illegible]	[illegible]	[illegible]	[illegible]	.055	
2		1.58	.90	[illegible]	.10	[illegible]	[illegible]				[illegible]	.063	
3		2.46	88	[illegible]	.11	[illegible]	34				123	.11	
4		3.36	.90	[illegible]	.11	[illegible]	34				[illegible]	.071	
		4.39	103		[illegible]						[illegible]	.077	
	[illegible]	5.41	102		[illegible]						[illegible]	.077	
	13 20	6.42	102	[illegible]	[illegible]		[illegible]				[illegible]	.077	
		7.44	1.01	[illegible]	[illegible]	[illegible]	[illegible]				[illegible]	.077	
		8.38	.94	[illegible]								.071	
		9.25	.87	[illegible]								.071	
		0.12	87			[illegible]	[illegible]				117	.063	
	[illegible]	91.00	.88	[illegible]		[illegible]	[illegible]				[illegible]	.063	
											[illegible]	.063	
Total	100	11.156			.11	34					125	Avg. .069	Avg.
Average		11.46											

[illegible]

CO_2 0.0 %

O_2 20.0

CO 0.1 [illegible] [illegible]

Plant ______________________ Date ______________________

Location ______________________ Operators ______________________

Test ______________________ Analyst ______________________

Moisture data

	Final weight (g m.)	Tare weight (g m.)	Weight of moisture (g m.)
Impinger #1	[illegible]	[illegible]	[illegible]
Impinger #2	[illegible]	[illegible]	[illegible]
Impinger #3	[illegible]	[illegible]	
Impinger #4	5		5
	Total		
	Moisture volume		[illegible] ml.

Particulate data

	Final weight (g m.)	Tare weight (g m.)	Weight of particulate (g m.)
Filter			
Beaker with (probenozzle) washings			
Cyclone flask			
Beaker with (impinger filter—holder) contents and washings			
	Total (gm.)		
	Particulates in (mg.)		

STACK SURVEY DATA

PLANT Pelly
RUN NO. 8 [illegible]
LOCATION [illegible]
DATE [illegible]
OPERATOR [illegible]
SAMPLE UNIT S/N
CONTROL UNIT S/N
AMBIENT TEMPERATURE, °F [illegible]
BAROMETRIC PRESSURE, IN. Hg 27.92
ASSUMED MOISTURE, Bw [illegible]

PROBE TIP DIAMETER, IN. [illegible]
PROBE LENGTH, FT.
PROBE HEATER SETTING

INITIAL LEAK TEST ☑
FINAL LEAK TEST ☑
METER TEMP. COMP. ☑

HEATER BOX SETTING, °F
ASSUMED MOL. WT. (DRY)
ASSUMED MOL. WT. (WET)
STATIC PRESSURE, IN., H_2O [illegible]
FILTER NUMBER [illegible]
CONDENSATE COLLECTED, ml [illegible]
VELOCITY, FT./SEC.
FLOW, SCFS
STACK DIAMETER
STACK HEIGHT

POINT	CLOCK TIME	DRY GAS METER, FT.³	VOL./PT.	PITOT, IN. H_2O ΔP	ORIFICE ΔH, IN. H_2O	DRY GAS TEMP. °F		PUMP VACUUM, IN. Hg GAUGE	BOX TEMP, °F	IMPINGER TEMP., °F	STACK TEMP., °F	ISOKINETIC %	
						INLET	OUTLET					MID	FINAL
	11.52	41.55											
1		0.63	.83	[illegible]	[illegible]			[illegible]	[illegible]	[illegible]	[illegible]	.055	
2		1.58	.90	[illegible]	.10	3[illegible]	[illegible]				[illegible]	.063	
3		2.[illegible]	88	[illegible]	.1	30	34				121	.11	
4		3.36	.90	[illegible]	.11	30	34				12[illegible]	.071	
[illegible]		4.39	103		[illegible]						125	.077	
[illegible]	[illegible]	5.41	102		[illegible]						[illegible]	.077	
[illegible]	13 20	6.42	102	[illegible]	.13		[illegible]				[illegible]	.077	
[illegible]		7.44	1.01	[illegible]	.13	3[illegible]	[illegible]				[illegible]	.077	
[illegible]		8.3[illegible]	.94	[illegible]								.071	
[illegible]		9.25	.87	[illegible]							117	.063	
[illegible]		0.12	87			3[illegible]	3[illegible]				[illegible]	.063	
[illegible]	[illegible]	[illegible]1.00	.88	[illegible]		3[illegible]	31				[illegible]	.063	
Total	[illegible]	11.15[illegible]			.11	34							
Average		11.46									125	Avg. .069	Avg.

[illegible]

CO_2 0.6 %

O_2 20.0

CO 0.1 [illegible] + Drager

Plant ____________ Date ____________

Location ____________ Operators ____________

Test ____________ Analyst ____________

Moisture data

	Final weight (gm.)	Tare weight (gm.)	Weight of moisture (gm.)
Impinger #1	103	100	3
Impinger #2	100	100	0
Impinger #3	1	0	1
Impinger #4	5		5
	Total		
	Moisture volume		9 ml.

Particulate data

	Final weight (gm.)	Tare weight (gm.)	Weight of particulate (gm.)
Filter			
Beaker with (probenozzle) washings			
Cyclone flask			
Beaker with (impinger filter—holder) contents and washings			
	Total (gm.)		
	Particulates in (mg.)		

APPENDIX 4

Calibration Data

CALIBRATION CERTIFICATE

DRY GAS METER

Date: Oct 24/84
Tech I.D.: G LANFRANCO
Console I.D.: 1A00

PARAMETER SUMMARY

	RUN NO. 1	RUN NO. 2	RUN NO. 3
T_a = ambient (wet test meter) temp.	66	66	
ΔP = press. diff. at wet test meter	-0.35	-0.40	
P_b = atmospheric pressure	30.23	30.23	
P_v = Vapor press. water at temp. T_a	0.645	0.645	
ΔH = press. diff. at orifice	1.0	1.5	
T_i = dry test inlet temp.	82	82.3	
T_o = dry test outlet temp.	72	72.7	
R_i = initial dry test vol.	955.417	963.858	
R_f = final dry test vol.	963.607	974.184	
V_i = initial wet test vol.	143.444	152.164	
V_f = final wet test vol.	151.923	162.810	
$P_W = P_b - (\Delta P/13.6)$	30.204	30.201	
$P_D = P_b + (\Delta H/13.6)$	30.304	30.340	
$T_W = T_a + 460$	526	526	
$T_D = [(T_i + T_o)/2] + 460$	537	537.4	
$B_w = P_v/P_b$	0.021	0.021	
CALCULATED Y VALUE	1.031	1.025	

CALIBRATION EQUATION

$$Y = \frac{V_f - V_i}{R_f - R_i} \left[(P_W/P_D)(T_D/T_W)\right] \cdot (1 - B_W)$$

Y(MEAN) = 1.028

AUTHORIZATION

Calibration Section

PITOT TUBE CALIBRATION S-TYPE

I.D. 6' Lear

DATE: January 24, 1985

ΔPR	ΔPS	$\sqrt{\frac{\Delta PR}{\Delta PS}}$ (.99)	AVERAGE
.02109	.02939	8386	
.02144	.03005	.8362	.8374
.02113	.02953	.8374	
.26201	.34552	8621	
.25887	.34661	.8556	.8584
.25825	.34427	.8575	
.52231	.69327	.8593	
.52099	.69283	8585	8586
.51995	.69204	.8581	
1.01826	1.35832	.8572	
1.01559	1.35776	.8562	.8564
1.01374	1.35705	.8557	
1.50160	2.00104	8576	
1.49960	2.00221	.8568	8565
1.49260	2.00031	.8552	
2.31031	3.18313	8434	
2.32321	3.18679	.8453	.8463
2.34987	3.18642	.8503	

CALIBRATION EQUATION

$C_R \sqrt{\Delta P_R} = C_P \sqrt{\Delta P_S}$ $C_R =$ 0.99

$C_P =$ ____________

ATTACHMENTS:

Calibration Curve ____________

Energy, Mines and Resources Canada
Énergie, Mines et Ressources Canada

Yukon
Department of Mines and Small Business

PELLY CROSSING WOOD CHIP BOILER

Final Project Summary

Canada/Yukon Conservation and Renewable Energy Demonstration Program

Project No.
3766-4-20

Project Locations:
Pelly Crossing

Project Manager:
Robert E. Collins

Date:
March 11, 1985

Technology:
Renewable Energy

Status:
Completed

Sectors:
Institutional, Business
Industrial, Residential

Jurisdiction:
Yukon

Simple Payback:
7.2 years

Purpose:

To demonstrate the viability of using an abundant local renewable resource to provide space and domestic water heating in remote Yukon communities.

Description:

A new school of 1,300 m^2 was originally to be heated by two oil-fired Bryan CL150 boilers, one providing 100% backup in the event the other failed. Instead a 350 kW Vyncke wood chip boiler, an underfed stoker and a 50 m^3 silo will provide the school with heat and domestic hot water. In the event of boiler failure, a propane fired boiler and a domesitc water heater will provide backup.

Contributors:

Department of Education, Government of Yukon	$30,000
Canada/Yukon	97,500
Total	$127,500

Demonstrated Benefits:

Projected annual fuel costs will drop from $16,740 for oil to $4,190 for wood chips. Local demonstration will give Yukoners maximum exposure to wood chip technology and increase the possibility of replication.

Further Information:

Robert E. Collins, Program Manager, Energy and Mines Branch, Economic Development and Tourism, Box 2703, Whitehorse, Yukon, Y1A 2C6 (403)667-5471.

Economic Analysis:

Wood chips will be sold to the school at $8.50/m³, a price equal to one quarter the price of oil on a delivered heat basis. Assuming an oil boiler efficiency of 60%, the price of delivered heat from fuel oil is $17.44/GJ and from wood chips $4.36/GJ. To meet the 960 GJ annually required by the school, $16,740 of oil would be needed as compared to $4,190 of wood. Incremental operating and maintenance costs and electricity to run the feed augers will cost $920, resulting in a first year savings of $11,630.

Technical Details:

Primary Heating - a 350 kW Vyncke model WW300S wood chip boiler equipped with an automatic underfed stoker and heat exchanger.
Storage - a 50 m³ line bottom, underground concrete silo equipped with a heat loop and a 30 cm feed auger.
Backup Space Heating - a Bryan CL-90 propane-fired boiler.
Backup Domestic Water Heating - a Jetglas 65-420 propane fired water heater.

Information Transfer:

A major information transfer plan was developed for the Pelly Wood Chip Industry projects. Included were tours of the demonstration facilities and seminars for potential users and producers, the publication and distribution of pamphlets, booklets and the final report and major media coverage.